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MODERN POWER GENERATORS

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STEAM ELECTRIC AND INTERNAL-COMBUSTION
AND THEIR APPLICATION TO PRESENT-DAY REQUIREMENTS

WITH MANY DIAGRAMS AND PICTORIAL ILLUSTRATIONS AND A SERIES OF COMPOSITE SECTIONAL MODELS

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VOLUME II

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ELECTRICAL GENERATORS AND MOTORS

ELECTRICAL GENERATORS AND MOTORS

It is not possible to explain the fundamental nature of electricity, notwithstanding the centuries of thought that have been expended on the subject. Recently the problem has been advanced another stage, but not as yet above the level of scientific speculation. For practical purposes it is fortunately unnecessary to understand the constitution of matter or its relation to electrical phenomena, since years of experience and investigation have established sufficient data to enable electrical engineers to design with confidence machines that will give to within a few per cent the calculated efficiency.

Before dealing with the practical aspect of the subject, a brief résumé will be given of the action of bodies under various electrified conditions, of which several exist.

FRICTIONAL ELECTRICITY

When two bodies are rubbed together they acquire certain electrical properties which differ from one another, and which vary in degree according to the nature of the substances. The phenomenon is best observed by choosing two materials such as a stick of sulphur and a piece of well-dried fur. If then the sulphur be rubbed with the fur it will be found to have acquired the property of attracting such light objects as small pieces of paper. Although not so readily detected, the fur may be shown to possess a similar property. When an object possesses this property, it is said to be charged with electricity and to be electrified. If now two sticks of sulphur are rubbed each with dry fur, and if the sticks are suspended near each other by means of silk fibres so as to prevent leakage of their charges, the two sticks will be found to repel one another. In the same way, by taking great precautions to prevent leakage a force of repulsion may be observed between the pieces of fur. The nature of the charges can be readily tested by other and more practical means. On suspending in a similar way a stick of sulphur and a piece of fur that have been rubbed together, the one will be

found to attract the other. This indicates a difference between the electrified state of the sulphur and of the fur, and shows also that whereas two similarly electrified bodies repel each other, those dissimilarly electrified attract one another. When, however, a piece of well-dried glass which has been rubbed with dry silk is suspended near a piece of sulphur rubbed with fur, instead of repelling each other as might be expected, they attract one another. This shows that the nature of the charges depends upon the substances used together.

Franklin has distinguished the two states by calling the charge produced on a glass rod when rubbed with silk "positive", and that produced on the sulphur when rubbed with fur "negative". In the list of substances given below, the arrangement is such that any body indicated is charged positively when rubbed with any one that follows, and is negatively charged by any that precedes it:—

Fur, wool, ivory, glass, silks, metals, sulphur, indiarubber, and celluloids.

Other terms have been used to distinguish the two kinds of charges; for example, glass rubbed with silk was said to be charged with vitreous electricity, and sulphur rubbed with fur was said to acquire a resinous charge. These terms are not satisfactory, as glass rubbed with fur acquires a resinous, that is, a negative charge.

The points regarding static charges of electricity to be particularly noted are that:—

Similarly electrified bodies repel one another whether both positive or both negative.

Bodies dissimilarly electrified attract one another.

Further, when two bodies are rubbed together the positive charge acquired by the one always equals the negative charge of the other.

The amount of the charges does not depend upon the friction. The purpose of the rubbing is merely to bring all parts of the substance into as intimate contact as possible. Under favourable circumstances, simple contact may be shown to give similar results. It appears from investigation that the charge distributes itself over the surface of the body. So far as the quantity of the charge is concerned, it is immaterial whether the body, say of a spherical form, is a thin shell or solid. In the case of a spherical ball the charge distributes itself uniformly over the whole surface, giving the same density of charge at any part. Where the curvature varies the distribution also varies, the charge gathering in greatest quantity at the places where the curvature is greatest. It is on account of this that a pointed body loses its charge rapidly to the surrounding air.

If a metal sphere be supported on an insulating stand to prevent the passage of electricity between it and the earth, and if a charged body be brought near it, the distribution on the sphere will be influenced very considerably. Suppose, for example, the charged body is a rod of glass that has been rubbed with silk and is therefore positively charged, the distribution on the sphere under the influence of the positive charge will be as shown in fig. 233. A negative charge will be attracted to the near side, and an equal positive charge repelled to the farther side of the sphere. A

well-known experiment, which demonstrates the results of the influence of an electrical charge upon a conductor, is made by suspending a pith ball on a silk thread and bringing near it a positive charge of electricity (fig. 234). The distribution on the pith ball is affected as above explained; but as the pith ball is free to move, and since dissimilar charges mutually attract one another while similar ones repel each other, and since also the negative portion of the charge is at a less distance than the positive portion, the resultant motion of the pith ball is towards the glass rod. Immediately contact takes place, the negative charge on the sphere becomes neutralized by part of the influencing positive charge on the glass rod. The pith ball is thus left with a positive charge and is repelled by the glass rod, which drives the pith ball away again. When the density of the charge is very great, the two bodies need not be brought into direct contact: the electrical stress may be sufficiently great to force a passage through the small layers of intervening air, and this it does with a crackling sound and the formation of sparks, due to the heat generated making incandescent the particles of metal and dust present.

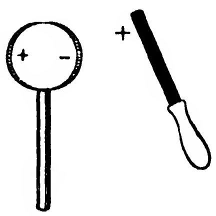


Fig. 233
Distribution of Electric Charges

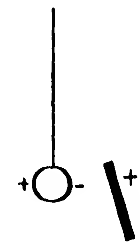


Fig. 234
Distribution of Electric Charge on a Pith Ball

Use has been made of the names Conductor and Insulator. As the names imply, a conductor permits of the ready passage of electricity, while an insulator does not readily do so. The terms are relative, as every body to a more or less extent allows of the passage of some of the charge.

Good conductors are the metals and water. The human body also conducts well. Such substances as ebonite, indiarubber, resin, silk, sealing wax, mica, glass, and air are non-conductors or insulators, or, as Faraday termed them, dielectrics. The conducting power of water explains the necessity in the experiments described of having the different substances free from moisture; a very small quantity of water allowing the charge to leak to the air as soon as formed.

In the same way, the insulating properties of glass, ebonite, and silk fibres suggest their use as handles or suspensions for the charged bodies. In practice the insulators most commonly used are indiarubber, dry, oiled, or waxed silk, cotton, vulcanite compounds, slate and marble, porcelain, mica, and glass. The quality of the surface is found to largely affect the insulating properties according to the readiness with which a film of moisture forms upon it. Vulcanite is found to give best results when the surface is not polished. On the other hand, slate is very generally polished and the surface waxed.

CONTACT AND CURRENT ELECTRICITY

To distinguish flowing currents of electricity from the static electricity already described, the term dynamic, or simply current electricity, is used. The investigations in 1789, of Luigi Galvani, professor of anatomy at Bologna, and the exhaustive researches of Alessandro Volta of Pavia in 1792, established the existence of a current

form of electricity differing widely from the static form discovered so many years earlier. Volta's experiments resulted, in 1800, in the very interesting discovery that two different metals, when brought into contact, became oppositely electrified. Thus, if two plates of zinc and copper fitted with glass insulating handles be brought into contact, the electrical conditions of both become altered. The zinc plate acquires a positive charge, and the copper a negative charge. By repeated experiments Volta succeeded in arranging the more common metals in a series showing the intensity and character of the currents produced when any two of the substances are brought into contact in air:

+ Zinc, lead, tin, iron, copper, silver, gold, platinum —.

In the series given, any metal in the presence of air acquires a positive charge in contact with any succeeding metal, and a negative charge with any metal preceding. Copper becomes negative in contact with zinc, and positive in contact with gold. The series forms also a scale of intensities; the positive and negative charges on the metals towards the extremes of the series attracting each other with a greater force than those of two metals nearer together in the scale. For example, copper becomes electronegative with zinc to a higher degree than with lead, and still higher than with tin; similarly it is more electropositive to platinum than to gold, and still more so than to silver. The phenomena are most probably due to chemical action between the metals in presence of the oxidizing agent air. If another gas, say sulphuretted hydrogen, be substituted for the air, the series already given becomes inverted, and an acid used instead of air produces increased results.

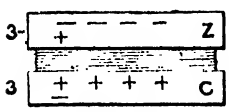


Fig. 235
Single Element of Voltaic Pile

The name electromotive force is given to the force of attraction between the electrical charges. The term voltage, derived from the name Volta, is also used to denote the electrical pressure exercised by the one charge upon the other. Potential is also frequently used to denote electrical pressure or voltage. Suppose that two metal plates, one of copper and one of zinc, are brought simultaneously into contact, with an intervening layer of felt moistened with dilute sulphuric acid, as indicated in fig. 235. As soon as contact takes place, the + and — charges of each plate, which until then were united, become separated, the negative charges accumulating on the outer surfaces, and the positive charges gathering at the acid layer. The zinc plate, however, is excited electrically to nearly four times the amount of the copper, with the result that the negative charge received by the copper is one quarter that received by the zinc, while the positive charge of the zinc is one quarter that of the copper. In the case of the zinc the one positive part of the charge neutralizes one of the four negative parts, so that the zinc is left with a resultant negative charge of three parts. In the same way the copper acquires an equal positive charge three times as great as would have been obtained by the excitation of the copper plate alone. By the simultaneous effects of the acid on the two metals an electromotive force is established between them, and when this force is exerted in overcoming a resistance, a definite quantity of metal is used up in chemical reactions. In the case under consideration the zinc plate would be gradually dissolved

away. Two plates excited in this way by a liquid form a galvanic couple, which has received the name galvanic or voltaic element or cell.

The potential or electrical tension between two plates is of a very small order, and can only be detected by very sensitive instruments. Volta found that by placing a number of elements in series so as to form a pile arranged as follows: copper, liquid, zinc, copper, liquid, zinc, and so on, the small effects of the individual cells were added to form an appreciable quantity, the potential between the ends being equal to the sum of the small individual pressures. Such an arrangement is called a voltaic pile. It commences with a copper plate and ends with zinc. The plates towards the middle of the pile show no electrical charge, since the positive and negative charges are equal there and neutralize each other. At the copper end of the pile the positive charge accumulates, and at the zinc end the negative charge gathers. Terminal wires are generally fixed to the ends or poles of the voltaic pile, the copper plate being the source of the positive current and the zinc that of the negative. When the wires are connected so as to form a continuous circuit through them and the elements, the circuit of the pile is said to be closed, similarly when the wires are not in contact the circuit is open. As soon as the circuit is closed a flow is established between the ends of the piles, the currents of opposite sign flowing to balance one another. From the copper plate the positive electricity flows through the wire to the zinc plate, while the negative flows through the wire in the reverse direction, as shown in fig. 236. The term galvanic current has been used to describe the flow of the electricity in the connecting wires. Since the electromotive force of each element tends to maintain a definite and constant potential between each pair of contiguous metallic plates, driving the positive current towards the extreme copper plate and the negative towards the extreme zinc, it is evident that this constant pressure will maintain continuous currents in the outside circuit, and that these same currents must also flow through the pile. The current flowing from the positive copper plate to the zinc, and in the pile from the zinc towards the copper, is called the positive current. The current flowing in the opposite direction is called the negative current. In speaking of the flow in the pile itself, the current passing from the zinc to the copper is termed positive. Since, therefore, the positive current starts at the zinc and passes through the pile towards the copper, the zinc is said to be an *electropositive* metal and the copper *electronegative*. Both end plates are called *electrodes*, the zinc being the *positive electrode*, carrying the negative pole of the pile, and the copper the *negative electrode*, carrying the positive pole.

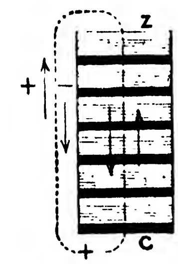


Fig. 236
Voltaic Pile

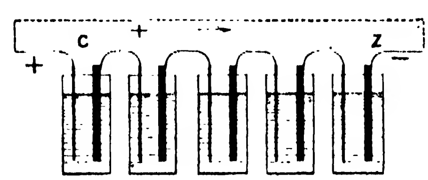


Fig. 237.—Battery of Galvanic Cells

To distinguish the positive and negative electrodes the terms anode and kathode are used respectively. In the example given of a zinc and copper element, the zinc is therefore the anode and the copper the kathode. Volta's pile, as illustrated in fig. 236, is not suitable for general purposes. The same effects may be produced in simpler and more convenient ways. In fig. 237 is shown a battery of galvanic cells corresponding

to the pile of voltaic elements. Each pair of zinc and copper plates is contained in a vessel, frequently of glass, and to separate the plates acidulate water is used, without the intervening layer of cardboard used in the voltaic pile. The copper of one element is connected directly to the zinc of the next element as before, and when the poles are joined by a thin wire, currents will flow round the circuit as indicated in the figure. As already explained, in each element of a particular kind a definite electrical pressure exists between its poles. If the zinc of a second element be then connected to the copper of the first, double the electrical tension, or voltage as it is called, will exist between the extreme poles of the two cells. The total voltage across the extremes of a battery of cells connected in this way is equal, therefore, to the sum of the voltages across the poles of the individual cells. It is the pressure across the poles that determines the quantity of current that will flow around the circuit in a given time. A very close analogy exists between the flow of water in a pipe under a given pressure, and the flow of electricity in a wire under a corresponding pressure or voltage. In the one case the hydraulic head or pressure, the quantity of water, and the resistance to the flow are comparable in the other with the voltage or electrical pressure, the quantity of current, and the total resistance of the circuit.

There are two kinds of resistance that must be considered when dealing with cells. First, there is the external resistance of the circuit joining the poles, for example the resistance offered to the flow of the current by the connecting wire; and second, there is the internal resistance of the cell itself. The external resistance, if consisting simply of a wire, will depend upon its length and diameter, and upon the metal used.

The internal resistance will depend largely upon the resistance offered to the flow of the current by the liquid separating the positive and negative electrodes, the greater the path through the liquid from plate to plate the greater the resistance. On the other hand, the greater the area of the liquid transmitting the current the smaller the resistance. There are other smaller resistances which must be added to obtain the total internal resistance of the cell, such as the resistance at the surfaces of the plates owing to the presence of layers of gas.

There is a definite relationship between pressure, resistance, and the quantity of current that flows in a definite time. It is therefore possible to compare the resistances offered by different metals, by measuring with suitable instruments the currents flowing in wires of the same lengths and diameters under the same pressures. Such comparisons are frequently made with copper as a standard, copper being the metal most generally used in practice. The number denoting how many times the resistance of the substance to the passage of the same current is greater or less than that of the standard copper, is termed the specific resistance of the substance. Iron has a specific resistance of about 6; that is to say, an iron wire offers about six times the resistance to the flow of current that a copper wire of the same length and diameter does. The resistance R of a wire is equal to the specific resistance Rs of the metal used, multiplied by the length L of the wire and divided by the area S of the cross section, thus:

$$R = \frac{Rs\ L}{S}.$$

In a memoir entitled *The Galvanic Chain*, published in 1827 by O. S. Ohm, the relationship between the pressure, current, and resistance existing in an electrical circuit was first established. This relationship, known as Ohm's law, states that the current generated in a circuit is greater or less according as the pressure is large or small, and according as the total resistance internal and external is small or great. The law may be expressed in the following ways:—

$$\text{(1) The current} = \frac{\text{Pressure}}{\text{Total resistance}}; \text{ or,}$$

$$\text{(2) The Pressure} = \text{Current} \times \text{Total resistance.}$$

Both the internal resistance of the cell and the external resistance of the circuit are included in the total resistance, so that formula (2) may be expressed thus:

$$\text{Pressure} = \text{Current} \times \text{Internal resistance} + \text{Current} \times \text{External resistance.}$$

One part of the total pressure is therefore expended in forcing the current through the cell itself against the internal resistance, leaving the remainder of the pressure to overcome the external resistance.

It is not necessary to enter here into the chemical phenomena with which the production of electrical currents in a galvanic cell are so intimately associated. In its chemical application the galvanic cell is put to various practical uses, particularly in its application to electrolysis.

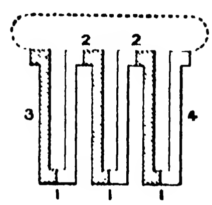


Fig. 238.—Thermo-pile Elements

Electric currents may be produced in other ways than those already described. If, for example, two different bodies, preferably two metals, are brought into intimate contact, a difference in electrical pressure will be established at the junction when its temperature is increased or decreased, and a definite though very feeble current will flow if the circuit be closed. As in the voltaic pile, the current intensity may be increased by placing a number of elements in series, as shown in fig. 238. A series of such contacts is called a thermo-pile, since it gives, in conjunction with a galvanometer for measuring the current that flows, a ready means of measuring quantities of heat. In fig. 238, if the soldered junctions 1, 1, 1 of the two different metals be gently heated, and the junctions 2, 2 be at the same time cooled to increase the effect, a difference of electrical pressure will be established in the extreme elements of the pile. Neither the galvanic battery nor the thermo-pile can be utilized in practice for the production of other than small currents. To produce large quantities of current other means must be adopted. The description given of the galvanic battery will, however, make what follows more readily understood, because no matter how the electrical current is produced, whether by the galvanic battery or otherwise, its behaviour is always the same, and further, the knowledge gained from observation of the galvanic currents has served as the basis of the construction and the later development of the large machines used at the present day for lighting and traction purposes. Many interesting experiments may be made with galvanic currents; and a few of the most typical that make the flow of the

electrical current evident to the senses may be mentioned here. If the bare ends of the wires connected to the poles of a galvanic cell are brought nearly together and then touched simultaneously with the tongue, two effects will be felt. The tongue will experience a prickling sensation and also a slightly acid taste, neither of which sensations will be detected if the wires are disconnected from the battery. The flow of the current from the battery may be made visible by means of a coil of wire and a compass, as shown in fig. 239, where the loop is arranged so that it encircles the compass and lies in the direction of the needle. One end of the coil may be joined to one pole of the battery, and the other arranged so that the circuit may be closed when desired. As soon as the circuit is closed the compass needle will suddenly deviate in one direction, and if the current be made to flow in the reverse direction through the coil by interchanging the ends of the wires at the battery poles, the deviation will take place in the opposite direction. A third experiment will show the chemical action of a current when passed through certain salts. By placing the ends of the wires connected to the battery poles upon a piece of blotting paper soaked in a solution of potassium iodide, care being taken that the wire ends are near one another but do not touch, then as soon as the current flows across the intervening gap the solution of salt will change colour to a deep blue. In practice this and similar actions are frequently made use of when it is necessary to distinguish the poles of a battery or dynamo. These are but a few of the many beautiful and instructive experiments that may be carried out with electric currents derived from a simple galvanic cell.

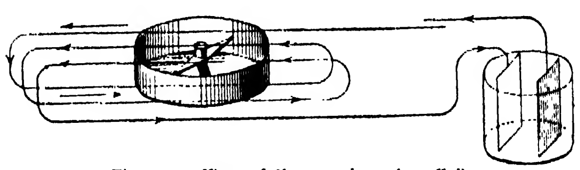


Fig. 239.—Flow of Current through a Coil

MAGNETIC EFFECTS OF CURRENTS

Of all the phenomena already mentioned, the one that has exercised the greatest influence upon the development of electrical machinery is the deviating effect of a flowing current upon a magnetized compass needle. This phenomenon, first observed in 1820 by Oersted, showed the close relationship that seems to exist between dynamic electricity and magnetism. Many scientists have sought, so far without success, to explain the relationship experimentally established. Ampère's investigations showed that not only static but also current electricity exercised the mutual attraction or repulsion forces already observed in the case of charges of static electricity. According to Ampère's theory, based on these investigations, magnetic phenomena are the result of the effects produced upon the molecules of the body by currents of electricity circulating around them. Arago, a French physicist, showed in 1820 that a current flowing in an insulated wire wound upon a bobbin acted upon iron filings in the same way as a bar of magnetized steel. The close connection of magnetic and electrical phenomena has been therefore realized from an early date.

PERMANENT MAGNETS

Until Arago made his memorable discovery it was thought that magnetism was a property possessed solely by certain substances, such, for example, as natural magnetic iron, which has the power of attracting certain bodies. Natural magnets of this kind may be made to impart the magnetic property to such a material as steel, which thus becomes an artificial magnet. When steel is used the magnetism is more or less permanent. If, however, soft iron is employed, the magnetism imparted will disappear almost immediately after the removal of the natural magnet. The phenomenon recalls the action of the suspended pith ball when in the presence of a static charge of electricity. The charges on the pith ball become separated under the influence of the static charge near it. For this reason the magnetism of the soft-iron bar is said to be induced.

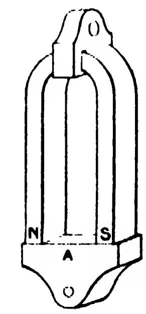


Fig. 240.—Horse-shoe Permanent Magnet

One of the earliest forms of the artificial permanent magnet is illustrated in fig. 240. It consists of a bar of steel bent into the form of a horse shoe, so as to bring the ends or poles conveniently near to one another. A piece of soft iron A serves as an armature or keeper, and is held by the magnet in contact with its poles. The poles are distinguished as north N, and south S, the north pole being magnetically positive and the south pole negative.

ELECTROMAGNETS

Arago's discovery made it possible to produce artificial magnets without the use of natural magnetism, and to realize much more powerful results, by winding a spiral of insulated wire around a core of suitable metal, such as iron, and by passing a current of electricity through the coils. When the current circulates through the spiral coil in the clockwise direction shown in fig. 241, the end of the core facing the observer becomes a south pole and the other end a north pole. One of the earliest rules devised to enable the relative directions of the magnetic and electric flows to be determined is as follows: *If the observer supposes himself swimming in the wire in the same direction as the flow of the current, and with his face turned towards the iron core, then his outstretched left arm will point to the north pole of the magnetized core, and his right hand towards the south.* The magnetic forces are exercised most strongly at the poles, and not only so, but around each of them for some considerable distance there is a magnetic field of rapidly diminishing intensity as the distance from the pole increases. The middle of the magnet remains almost unaffected, and at one part, called the neutral line, there is no effect observable. If the soft-iron core be replaced by one of steel, the magnetism of the core induced by the current in the coil becomes more or less permanent. A steel needle

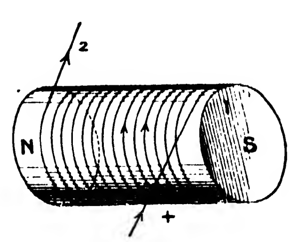


Fig. 241

Simple Electromagnet

magnetized in this way exhibits all the properties of the magnets produced in the ways previously mentioned. When suspended, for example, at its middle it will behave like a compass needle, directing its north pole towards the north pole of the earth. As already explained, if a continuous spiral be wound around a long thin core and a current passed through the coils, the opposite ends of the core will become north and south poles respectively. If, now, the core and spiral be supposed bent, as indicated in fig. 242, the result will be a horse-shoe electromagnet, with the continuous coils on the two magnet limbs apparently running in opposite directions. All magnets produced by the flow of a current around a core, of whatever form, are called electro-magnets. There is a close analogy between the attractions and repulsions of magnetic poles and of electrical charges. Poles of north and south polarity attract each other, while similar poles are mutually repellent.

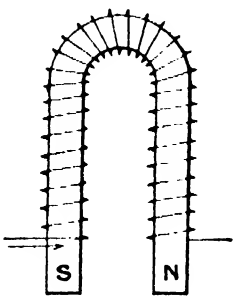


Fig. 242.—Horse-shoe Electromagnet

SOLENOIDS

Ampère showed that a simple spiral of insulated wire through which a current flowed might be considered as a magnet although no central core of iron was present, and that the rule already given for determining the direction of the magnetism induced was equally applicable. Suppose such a spiral, wound as shown in fig. 243, is suspended with its ends pivoted each in contact with one pole of a battery so that it may rotate freely as indicated. The flow of the current will then induce a magnetic field of north polarity at one end of the spiral which will swing round towards the north pole of the earth, while at the other end of the spiral the magnetic field will be of south polarity, and will be directed towards the south terrestrial pole.

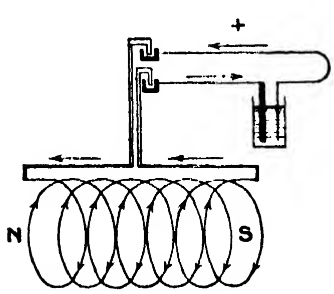


Fig. 243
Ampère's Solenoid

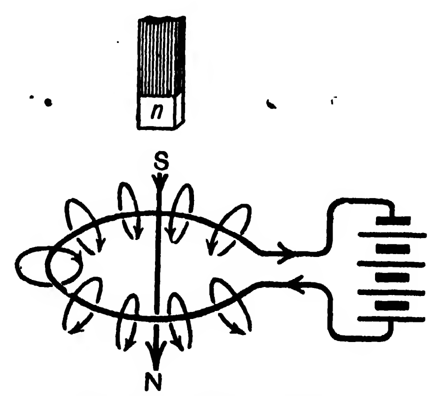


Fig. 244.—Single-loop Solenoid

Although a single spiral has been shown in the figure, similar results may be obtained by insulated layers of spirals wound continuously in the same direction, one upon the other, as is frequently done in practice to increase the effects. If a current from a battery be passed through a loop of wire, as shown in fig. 244, the enclosed space will become magnetically stressed, and around the wire there will be as it were a magnetic whirl indicated by the arrows. When the current passes in one direction the whirl will have a definite rotation, which will be reversed whenever the direction of the current in the wire is reversed. Suppose, for example, the current is flowing through the loop in a clockwise direction when viewed from above. If, then, the observer looks along the

wire in the same direction as the flow of the current, the magnetic force may be considered as whirling in a clockwise direction around the wire, and vice versa. Arago's convention, already described, helps still further to explain the behaviour of solenoids. An observer supposed to be swimming in the wire in the same direction as the current would, if he turned his face inwards towards the centre of the loop, have the north pole of the solenoid in the direction of his outstretched left arm, and the south pole towards his right. If, therefore, a magnet be held as shown, with the north end downwards, it would be attracted by the south pole of the solenoid. An interesting and now historic experiment is illustrated in fig. 245. The solenoid consists of several turns of wire wound upon a bobbin, and has its ends fixed to zinc and copper plates respectively. The bobbins and plates are arranged to float in a glass vessel of acidulated water, the whole arrangement thus forming a floating battery. Owing to the circulation of the current, one end of the coil becomes a south-seeking pole and the other north-seeking, so that if a magnetized bar of steel be brought near it the coil will be attracted or repulsed as the case may be. For example, when the north pole of the magnet is presented to the south pole of the solenoid, the coil will pass up the bar to its middle. If, on the other hand, the north pole of the magnet is directed to the north pole of the solenoid and forcibly thrust into it and then released, the coil will move away, free itself from the magnet, then swing round until its south pole faces, and advance again over the bar until it reaches the middle. Two solenoids behave exactly in the same way as a solenoid and a magnet; like poles repelling, and unlike attracting each other.

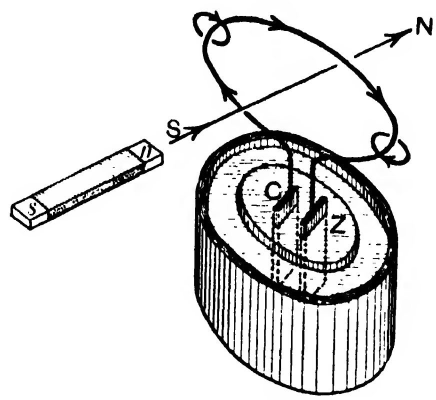


Fig. 245.—Floating Solenoid

MAGNETIC INDUCTION

When a pole of a magnetized steel bar is brought towards an opposite pole of a solenoid in which a current flows, the magnet is attracted and, as it were, sucked into the interior of the solenoid. This fact immediately suggests the converse, namely, that if the magnet be thrust into the solenoid a current will circulate in the circuit of the coils when no battery is present. The experiment can be easily carried out, as in fig. 246, by placing a galvanometer in the solenoid circuit to record the flow of the current. As the magnet approaches and enters the coil the needle of the galvanometer will deflect, and similarly when the magnet is withdrawn, but the deflection will be momentary, and will occur only when the magnet is moved either in or out. Currents of this kind are said to be induced; they arise from the crossing of the coils and the magnetic field, which results as it were in a magnetic whirl around

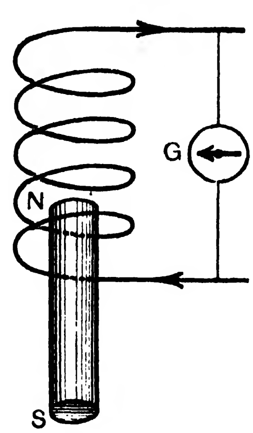


Fig. 246
Flow of Induced Currents

the wire, and this induces a current so long as the magnetic field is moved across the wire.

The current induced when the magnet is inserted is an inverse one, that is, it circulates in a direction opposite to the current that would be required to produce the polarity of the magnet as inserted in the solenoid. When the magnet is withdrawn, the induced current is a direct one. As first enunciated by Lenz, the law known as Lenz's law states that "the direction of the induced currents is such as to set up a magnetic field which will tend to retard the change to which the induction is due". Thus, in the case illustrated (fig. 246), if the north pole of the magnet be rapidly thrust into the solenoid the induced current will flow in a counter-clockwise direction, setting up a north pole at the upper end of the solenoid which would tend to repel the magnet and thus retard the change to which the induction is due. It should be noted that the magnet loses none of its power in inducing these currents.

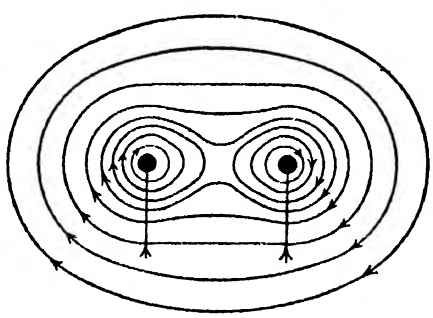


Fig. 247.—Magnetic Attraction between Parallel Conductors

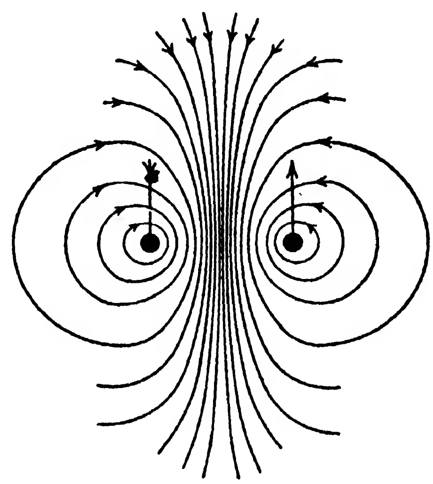


Fig. 248.—Magnetic Repulsion between Parallel Conductors

ELECTRODYNAMICS

Electrodynamics is that part of the science which deals with the mutual forces exerted by electrical currents. Ampère, in 1821, discovered that conductors in which currents flowed were mutually repelled or attracted according to definite laws, and that the mutual actions were due to the magnetic whirls set up around each conductor by the flow of the currents. In fig. 247, for example, which shows a section of the conductors passing at right angles through the paper, the currents are supposed to flow in both conductors downwards, and the courses of the magnetic lines of force are indicated by the curved lines. In fig. 248 the direction of the flow in the right-hand conductor is reversed, and thus the whirls rotate in opposite ways. More lines of force will in this latter case pass between the conductors than in the former, and the stress in the intervening space will be greater, so that the conductors will be forced apart, while in the former case they will move towards each other.

Two parallel conductors, therefore, in which currents flow, attract or repel one

another according as the currents flow in the same or in opposite directions. This also applies to the case of conductors which cross one another obliquely, as shown in plan in figs. 249 and 250. In the case illustrated, currents are supposed to run in the same direction in the wires 1, 2, and 3, 4, which may or may not be parts of the same circuit.

From what has been said above, it will be clear that in the intervening spaces 1, 5, 3, and 4, 5, 2, bounded by conductors in which the currents flow as indicated,

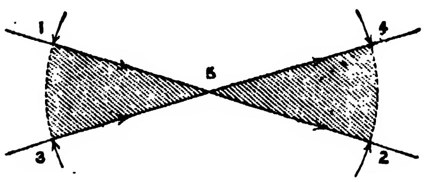


Fig. 249.—Magnetic Stress between Crossed Conductors

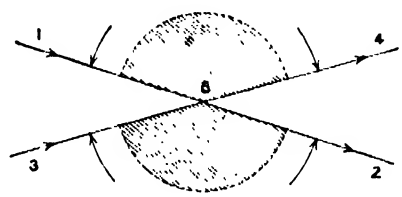


Fig. 250.—Magnetic Stress between Crossed Conductors

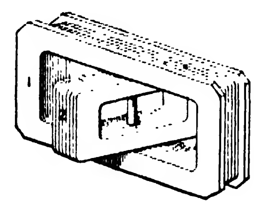


Fig. 251. Magnetic Stress between Crossed Coils

there will be a reduction of the magnetic stress, and therefore a tendency for the conductors to be forced together about the intersection 5. The two conductors will, under the actions of the magnetic fields set up around them, tend to set themselves in such a way that their currents flow in as nearly as possible the same paths.

Fig. 251 shows two coils wound on frames, the pivoted one centrally within the other. If, then, currents are passed round the coils, the moving frame will swing into the plane of the fixed one, so as to bring the directions of the two currents parallel. These reactions are made use of in many electrical measuring instruments.

MAGNETO-ELECTRIC MACHINES

The first successful attempt to make use of induced currents was made by Pixii in 1832 with the apparatus illustrated in fig. 252, which contains practically all the essential parts of the powerful generators of the present day.

The coils 1, 1 in which the currents are induced are wound upon the limbs of a soft-iron horse-shoe core, and a permanent horse-shoe magnet is supported on bearings in front of the coils, so that its poles may be rotated in front of those of the bobbin. Each time the permanent-magnet poles sweep past the soft-iron ends of the bobbins a momentary current is induced in the circuit of the coils; but since a north pole and a south pole sweep alternately past the coil cores it is clear that the direction of the induced current will be reversed each half-revolution, and that the strengths of the induced currents will vary during each half-revolution from zero to a maximum and back to zero, when the direction of the flow will be reversed. In fig. 253 a view is given looking towards the coil ends, in front of which the permanent-magnet poles

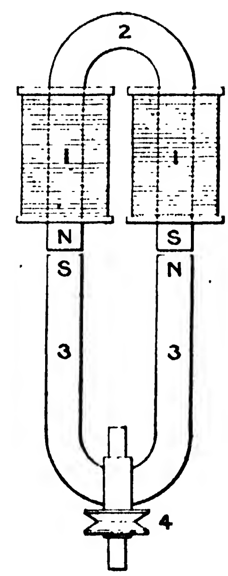


Fig. 252. Pixii Electric Generator

are supposed to be rotated, while fig. 254 illustrates the variation in the strength of the induced current as the permanent magnet makes one revolution. The action of one only of the permanent-magnet poles, say the north pole N, need be considered, since the south pole merely doubles the effects throughout the cycle. When the north pole N is moving through the position A, the rate at which the magnetic lines cut the coil cores is not changing, and there is therefore no induced current. At the point A, therefore, fig. 254, zero current is indicated.

As N sweeps towards and then past the coils at position B, the induced current increases to a maximum, and then decreases until at position C the current is again zero. After passing C the north pole N approaches the other limb of the coil, so that the current induced is in the opposite direction to the previous one. This is indicated in the diagram by the extension of the curve being continued under the zero datum line. As the north pole passes position B the current is again a maximum but in the reverse direction, and when the revolution is completed at the point A the current has fallen to zero, and thereafter the cycle is repeated.

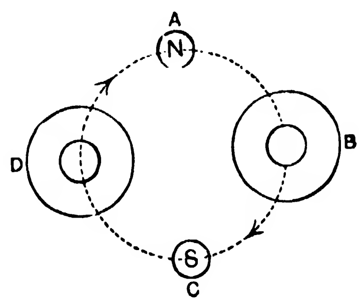


Fig. 253.—Rotation of Magnet Poles across a Pair of Coils

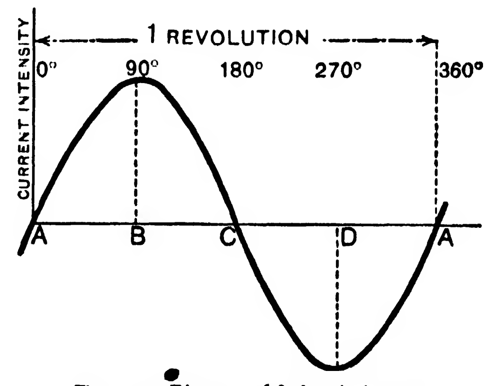


Fig. 254.—Diagram of Induced Currents

A current which fluctuates in this way and alternately changes its direction is called an alternating current. The intensity of the induced current in such magneto machines depends upon the rate of change in the number of the magnetic lines cutting the coils, and therefore upon the speed of rotation and upon the strength of the magnetic fields. Very many different types of magneto machines have been devised from time to time, but in all the underlying principles are the same. After the publication of Pixii's machine, the arrangement was improved by rotating the bobbins instead of the magnets, which in large machines were of a considerable weight.

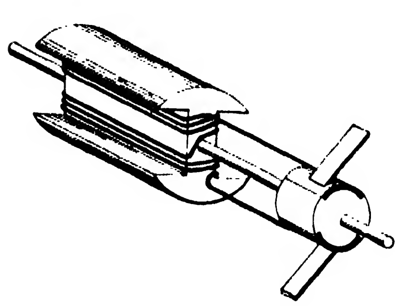


Fig. 255. Magneto Armature

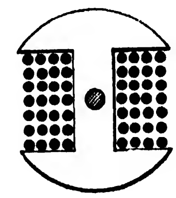


Fig. 256.—End Section of Magneto Armature

In order to more completely utilize the magnetic field, Werner Siemens in 1856 introduced the wound-shuttle armature, indicated in fig. 255, and in section in fig. 256, and shown in fig. 257 in position between the poles of the permanent magnet. Instead of one permanent magnet extending the whole length of the armature, which is impracticable, Siemens introduced a number of magnets side by side, as shown in fig. 258. In

the case of Pixii's machine the currents induced are alternating, which for many purposes is a disadvantage, as, for example, in electric lighting, when it is desired to have the current flowing continuously in one direction. This is effected by the addition of a commutator, which reverses the direction of the induced current in the coil once each revolution, so that the currents induced at each half-revolution then flow in the same instead of opposite directions.

In the Siemens and other

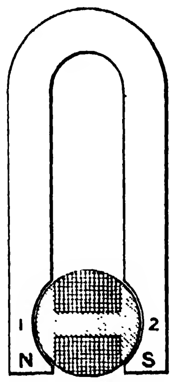


Fig. 257.—Side Sectional Elevation of Magneto Armature and Field Magnet

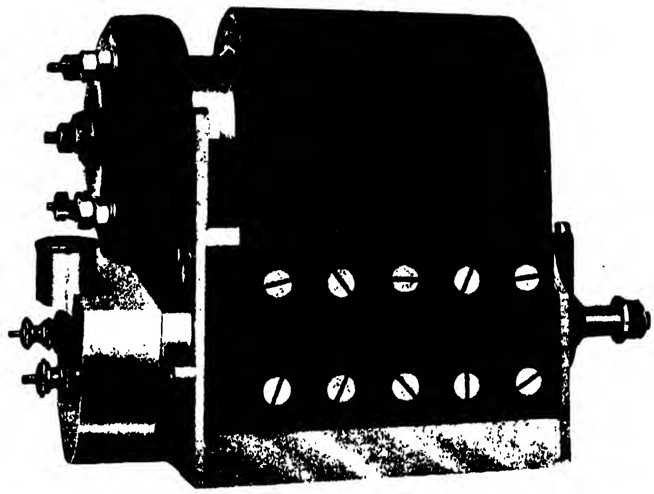


Fig. 258.—High-tension Magneto Machine (Speedwell)

simple magneto machines, two currents only are induced during each revolution, and one of these requires to be reversed. Fig. 259 shows the end view of the commutator, which is supposed to be fixed upon the spindle of the rotating armature, and to have its two insulated metal portions connected respectively to the ends of the armature coil; 4 and 5 are metal contacts or brushes rubbing gently on the surface of the armature, and 6 is the external circuit, which may include a galvanometer to indicate the flow of the current, or an electric lamp. Suppose a current commences to flow in the coil, and that it enters the segment 1. Its course will then be through 4, 6, and 5 to the segment 2 connected with the other end of the coil, thus completing the circuit. In the position of the armature shown in this figure the intensity of the induced current is at its maximum.

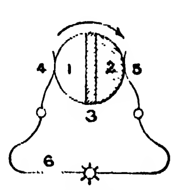


Fig. 259

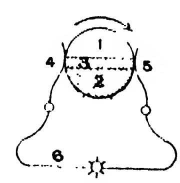


Fig. 260

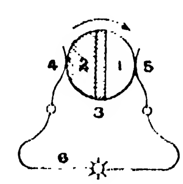


Fig. 261

Simple Commutator in Consecutive Positions

When the commutator reaches the position shown in fig. 260, that is, when the armature has turned through 90°, the current will have fallen to zero, and the brushes will be on the insulated portion. At this point the required reversal should take place, since the current will now commence to enter from the coils through the segment 2. Fig. 261 shows the position when the armature has passed through 180°. The current from the coils now enters segment 2, but this segment is now in contact with the brush 4, so that so far as the external circuit is concerned the direction of the flow remains unaltered.

Currents flowing continuously in the one direction are called continuous currents to distinguish them from alternating currents.

There is as before a fluctuation of the current from zero to a maximum twice during each revolution, but, as indicated in the diagram fig. 262, no portion of the current falls below the zero line. The dotted portion of the alternating-current curve has been reversed, and now lies above the zero line.

For electric lighting and many other purposes the single fluctuating currents, already described, are of no use. Such a lamp placed in the circuit would give a fluctuating

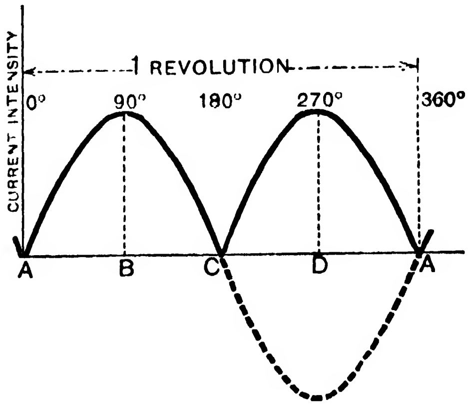


Fig. 262. Diagram of Single Commutated Current

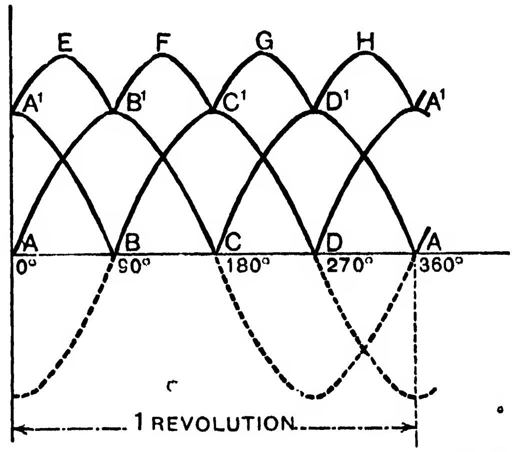


Fig. 263.—Diagram of Two Commutated Currents

light, as the current rose to its maximum and fell to zero. It is possible, however, by suitably winding the armature with a series of coils, to make the fluctuations so rapid and of so small a range that for all practical purposes the voltage in the circuit, and therefore the light of the lamp, will appear continuous. This will be more readily understood by considering, as before, what happens during one complete revolution of the coil. Fig. 262 shows the fluctuations in a single coil. If now the wire on the armature is continued so as to form a coil at right-angles to the first, the voltage in this second coil will reach the maximum when the voltage in the other is zero. In fig. 263 the two curves A B′ C D′ A and B C′ D A′ are indicated displaced by 90°. The resultant curve, which is obtained by adding the amounts of the two curves at that particular point, is shown by the A′ E B′ F . . . line. It will be noted that the range of fluctuation is much diminished, and that the voltage now never falls to zero. The fluctuations also are more rapid, there being now four instead of two, that is two to each coil.

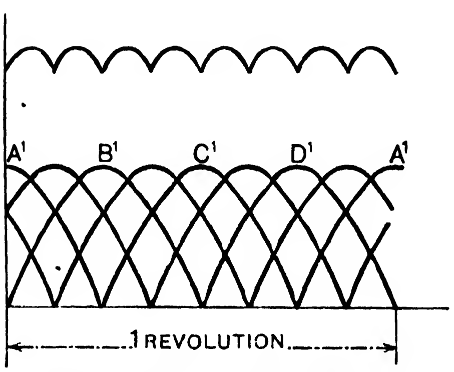


Fig. 264.—Diagram of Continuous Current

Fig. 264 shows the curve of voltage resulting from the use of four coils symmetrically arranged at 45° intervals. The resultant curve is rapidly approximating to a continuous straight line.

Pacinotti, in 1864, exhibited the first small machine with an armature of the type now known as ring wound. To Gramme, however, belongs the credit of producing the ring-wound-armature dynamo in a practicable form. Ring-wound armatures are

accordingly very generally known as Gramme rings. An armature of this type consists of a cylindrical soft-iron ring or core (fig. 265), wound, as shown, with a series of coils 2, 2 connected the one to the other by means of the segments on the commutator. The coils thus form one complete and continuous circuit with the junctions of adjacent coils connected to the commutator segments, there being therefore as many segments as coils on the armature. The whole armature revolves in the magnetic field of the permanent

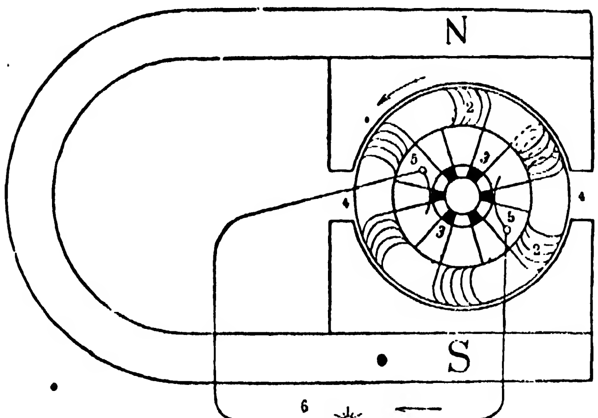


Fig. 265.—Elements of Gramme Ring-wound Dynamo with Permanent Field

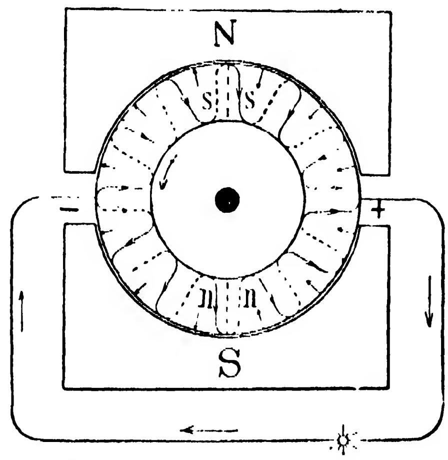


Fig. 266.—Flow of Currents in Gramme Ring Dynamo

magnet N S. Brushes 5, 5 press against the commutator and allow the currents generated to flow into the external circuit 6. The brushes are placed opposite the neutral parts of the ring as shown in fig. 266, which explains the action. Poles of north and south polarity are induced in the soft-iron core by the permanent poles of opposite polarity, so that the core may be regarded as two magnets with their like poles in contact as at *n*, *n* and *s*, *s*. At the intermediate points the magnetism is zero. The commutator brushes are accordingly placed on this neutral line. From the north permanent pole the magnetic lines of force pass towards the south pole, but instead of passing directly across through the central air space, the lines become concentrated in and pass through the soft-iron core, which offers a resistance to their passage much less than air. This magnetic flow is illustrated in fig. 267. If now the armature be rotated, the wires on the outer surface will cut the magnetic lines of the field entering the core, while the wires on the inner surface will not, since the field only leaves the core again at its surface. These inner conductors serve only as returns for the surface wires. If the direction of the armature rotation be counter clockwise the current in the coils on the upper half of the ring will flow towards the right marked + (fig. 266). In the lower half of the armature coils the flow of current will also be towards the right, so that one side of the armature will be at a higher potential or voltage than the other, and a continuous current will flow in the outside circuit in the direction indicated by the arrows.

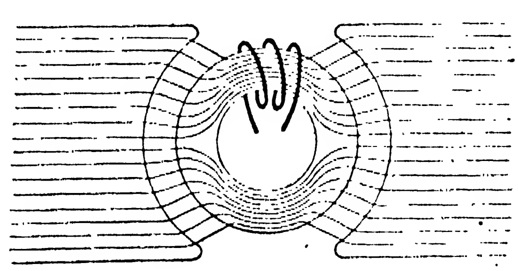


Fig. 267.—Magnetic Flow through Armature Core

DYNAMO-ELECTRIC MACHINES OR DYNAMOS

One serious disadvantage has been common to all the electromagnetic machines so far described, namely, the use of permanent magnets to produce the magnetic field in which the armature is rotated. With permanent magnets it is not possible in practice to generate other than small quantities of electrical energy, owing to the limitations of the size and strength of permanent magnets. To overcome this difficulty, Mr. H. Wilde, of Manchester, in 1866, introduced a dynamo in which the permanent steel magnet was replaced by a powerful electromagnet with a soft-iron core. In Wilde's machine a small separate auxiliary magneto was used to supply the current for the excitation of the field-magnet coils of the principal machine. By the combination in this way of the small electromagnetic machine with permanent magnets, and the large machine with electromagnets, it has become possible to construct generators of powers to suit any demands.

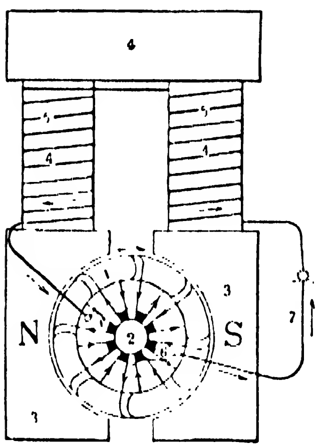


Fig. 268. Dynamo with Electro-Magnetic Series-wound Field

A most important advance was made by Werner Siemens, who dispensed with the use of a separate auxiliary magneto-electric machine for exciting the field-magnet coils of the large machine. Siemens found that by passing a portion of the armature current through the coils the machine could be made to produce its own magnetic field. The soft iron of the magnet core retains permanently a small amount of magnetism which is sufficient to generate a small current in the armature as soon as it is rotated. This small current passing through the coils increases the magnetic field, which in turn increases the armature current, and so on, until the soft iron of the magnet core is so saturated that it cannot carry more magnetic lines. Gramme at once appreciated the importance of Siemens's dynamo-electric principle, and applied it practically to one of his ring-wound machines. Fig. 268 shows the essential parts of the Gramme machine, arranged diagrammatically to illustrate the action. Comparison with fig. 265 will show that the wire from the one brush of the commutator is first coiled continuously round the iron limbs of the field magnet before passing on through the external circuit back to the other commutator brush. There is thus a continuous circuit through the armature and field coils. This type of dynamo is said to be series-wound, and all the current generated passes through the few turns of thick wire on the magnet limbs to produce the required magnetic field. The strength of a magnetic field, that is, the number of magnetic lines of force produced, is determined up to a certain limit by the total number of turns of the coil and by the current passing through them, that is, the magnetic field depends upon the ampere turns. A certain strength of field may be obtained with a large current passing through a few turns or a small current passing through a large number of turns. Since the total current generated is passed through the coils in a series machine it is necessary to use a heavy wire capable of safely carrying the large current, and a few turns only are required.

Shunt-wound machines make use of the second method of winding with many turns of fine wire carrying a small current, which is only a small fraction of the current circulating through the armature and the external circuit. Fig. 269 shows the diagrammatic arrangement of a shunt-wound machine. The external circuit is connected as before in fig. 265 to the armature brushes, while the field coils comprise another circuit in parallel with the external circuit, and also connected to the armature brushes. As the resistance in the field coils is great compared with the resistance of the external circuit, the current in the magnet coils will be proportionately small.

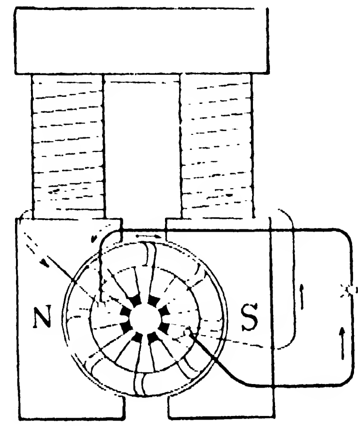


Fig. 269.—Shunt-wound Dynamo

When a series-wound machine is run at its normal speed with the external circuit open, no current flows, and therefore there is no voltage across the brushes of the machine. As soon as the circuit is completed, a small but rapidly increasing current flows as the magnetism builds itself up. In the diagram, fig. 270, in which horizontal lines represent the circuit resistance and vertical lines the corresponding voltages, it will be seen that when no current flows, that is, when the resistance is infinite, there is no voltage, and, further, until the external resistance has fallen below a certain critical point, depending upon the nature of the machine, the magnetism will not build up and the machine is not up to this point self-exciting. When, however, a larger current is allowed to pass, the voltage rapidly increases, and this continues until the point beyond which the magnetism of the cores cannot be increased, owing to the saturation of the soft iron used and to other internal reactions. Thereafter an increased demand for current involves a fall of pressure at the dynamo terminals, as shown by the gradual descent of the curve. The point to be more particularly noted is that, up to a certain point, the dynamo suits itself to the load on the outside circuit, supplying more current and giving the necessary increase of pressure as the load on the line is increased and its resistance therefore diminished. Curves of this kind are known as characteristic curves. When plotted for any particular machine, by noting the readings of an ampermeter in the circuit and a voltmeter across the dynamo terminals, they supply much information regarding the machine. A shunt machine gives a characteristic differing greatly from that of the series-wound machine. There is always a closed circuit through the armature and the field coils, although the external circuit may be open, and when the machine is running there is a more or less definite voltage, depending upon the construction of the machine, whether the outside circuit is open or closed. The characteristic shown in fig. 271 gives for zero current

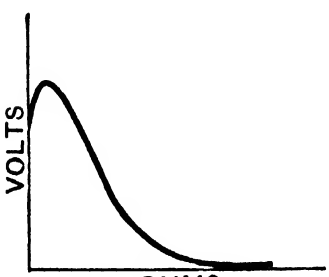


Fig. 270.—Characteristic Curve of Series-wound Dynamo

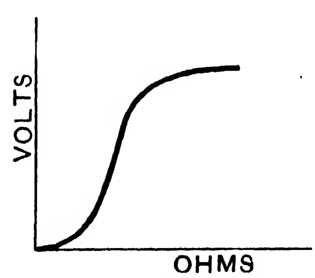


Fig. 271.—Characteristic Curve of Shunt-wound Dynamo

in the outside circuit the full voltage. As soon, however, as the load on the machine is increased by decreasing the outside resistance, a larger proportion of the current will flow to meet the demand and a smaller proportion will flow through the field coils, and owing to this and other causes the magnetism will fall, and with it the voltage of the machine. This is indicated by the fall of the curve, fig. 271. When, within certain limits, an extra demand for current is made upon a shunt machine the pressure falls. With a series machine, on the other hand, the pressure rises. It is possible by suitably combining these two methods of winding to make the rise of pressure compensate the fall, and thus to keep the pressure constant for a considerable fluctuation of load. Dynamos so arranged are said to be compound-wound. Fig. 272 shows the two coils upon the field magnets, one consisting of a few turns of heavy wire in series with the outside circuit, and the other shunt coil in parallel. Sometimes the series winding is increased when the machine has to supply current to lamps, or machines working at the end of a long line having some considerable resistance. Machines of this kind are said to be overcompounded.

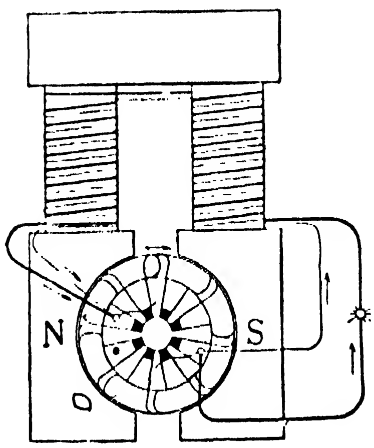


Fig. 272.—Compound-wound Dynamo

Series-wound dynamos are ordinarily employed in cases where a certain number of arc lamps require to be supplied with a constant current and at a voltage varying with the number of the lamps.

Shunt dynamos give, within certain limits, automatic regulation and a constant voltage suitable for many purposes.

The compound-wound machine is universally employed where a constant pressure is required across the terminals of the machine on the lines, without the necessity of varying the speed of rotation as the load fluctuates, as, for example, when incandescent and arc lamps are used upon the same circuit. The terminal voltage in both shunt and compound machines may be regulated by inserting an adjustable resistance in series with the shunt resistance on the field coils.

CONTINUOUS-CURRENT DYNAMOS

The distinction between continuous and alternating currents has already been explained. It now remains to describe more particularly the way in which the armature coils are wound to obtain the best results. Instead of the ring winding, which involves a considerable portion of ineffective wire, namely, the wire on the inner surface of the ring, it is very customary to use another winding which has not this disadvantage. This armature, which is said to be drum-wound, and was first invented by Hefner Alteneck, in 1872, has all its conductors arranged upon the surface of a cylindrical core or carcass, and in the direction of its length. The only ineffective wires are then the connections of the various coils across the ends of the cylinder, as each longitudinal conductor is in a

position to cut the magnetic field. One simple coil is shown in the diagram, fig. 273, rotating about the axis A, B in a clockwise direction, and between a pair of magnet poles. Under the conditions illustrated a current will flow in the rectangular coil in the direction of the arrows, its intensity being a maximum when the conductors are crossing the middle of the pole faces, and zero when the conductors are just entering or leaving the magnetic fields. The current will flow in one direction through the coil because the conductors forming the two sides of the loop move through the magnetic field, one in the upward direction and the other downwards. By means of a commutator, as already explained, the reversal of current may be obviated in the external circuit when the position of the opposite conductors becomes reversed. Other similar coils arranged around the cylinder would produce their maximum currents at different moments, depending on their relative positions, so that if these coils were connected together, as in the Gramme ring, to form a continuous closed circuit, some coil of the winding would at any moment be delivering a current through a corresponding pair of armature segments.

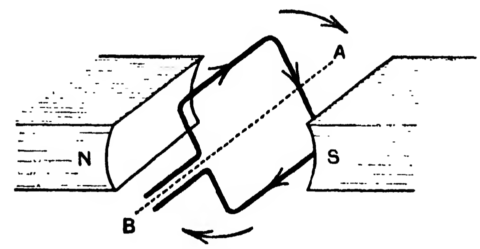


Fig. 273.—Rotation of Single Coil in a Magnetic Field

Some idea of the nature of a drum winding may be obtained from the diagrammatic sketches of the commutator end of the armature, and the perspective view, figs. 274 and 275. Around the circumference of the drum are arranged sixteen conductors constituting eight coils joined in series, and also connected at their junctions to eight commutator segments lettered in the figures *a b . . . h*. Starting from any one of the commutator

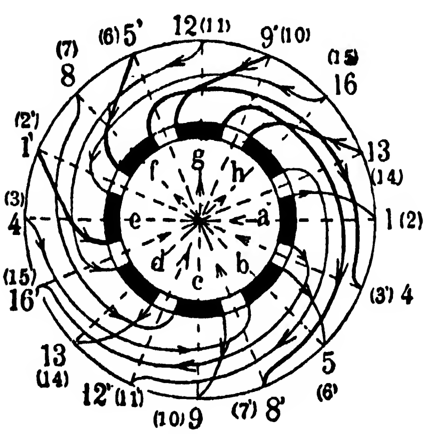


Fig. 274.—Commutator End of Drum Winding

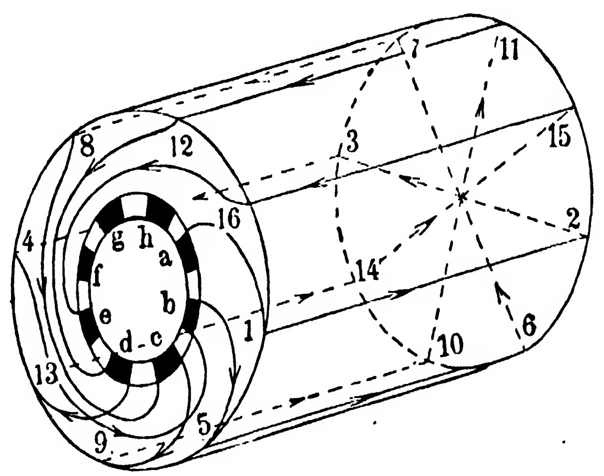


Fig. 275.—Armature Drum Winding

segments there is a choice of two paths through the winding to the opposite segment, so that the eight coils may be considered as two groups of four coils each on either side of the diameter through the two commutator segments. To the one group, in the case illustrated, belong the conductors marked 1 to 16, the numbers 1′ to 16′ being used to indicate the second group. The figures in brackets—thus (14)—indicate the parts of the conductors at the armature end away from the commutator, the figures without brackets being used for the ends near the commutator. Starting at segment *a* and tracing the

path of the current through the winding, the current will pass across the end connecting wire to 1, then along the surface conductor 1, 2, across the end connection 2, 3, and along the opposite surface conductor 3, 4, back to the commutator end. From 4 the current passes through the end connection to the next commutator segment *b*. Starting now from *b*, a similar path may be traced round the armature to *c*, and so on for each

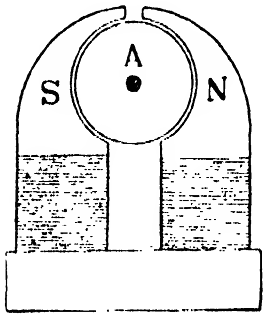


Fig. 276. Overtype Dynamo Arrangement

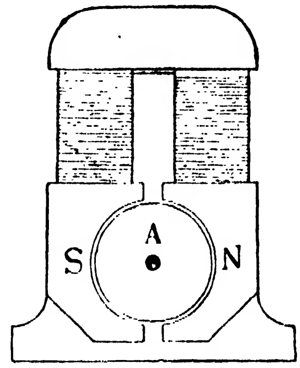


Fig. 277.—Inverted Dynamo Arrangement

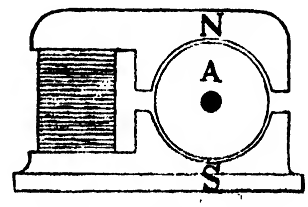


Fig. 278.—C Type Dynamo Arrangement

commutator segment. Commencing at segment *a*, which may be considered in contact with one of the brushes, the flow of the current will be as follows:—

$$a\ 1\ (2)\ (3)\ 4\ b\ —\ b\ 5\ (6)\ (7)\ 8\ c\ —\ c\ 9\ (10)\ (11)\ 12\ d\ —\ d\ 13\ (14)\ (15)\ 16\ e.$$

e is the opposite segment and may be considered in contact with the second brush. One half of the segment has been used in passing through the first group of four coils. The

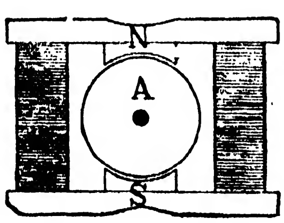


Fig. 279.—"Manchester" Type

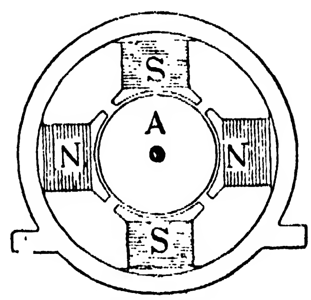


Fig. 280.—Stationary Field Coils

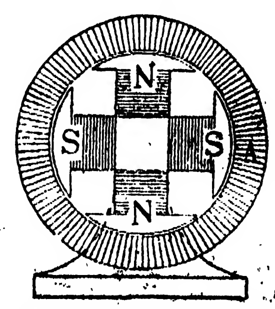


Fig. 281.—Rotating Field Coils

Arrangement of Four-pole Dynamos

second half of the commutator serves for the remaining four coils. Thus, starting again at *a*, the path to the opposite segment would be in the reverse direction as follows:—

$$a\ 16'\ (15')\ (14')\ 13\ h—h\ 12'\ (11')\ (10')\ 9'\ g—g\ 8'\ (7')\ (6')\ 5'\ f—f\ 4'\ (3')\ (2')\ 1'\ e.$$

In the diagram the conductors of the second group are indicated as being interposed between those of the first. They might equally well, however, be superposed. Since in a bipolar machine there are two paths through the armature, from one brush to

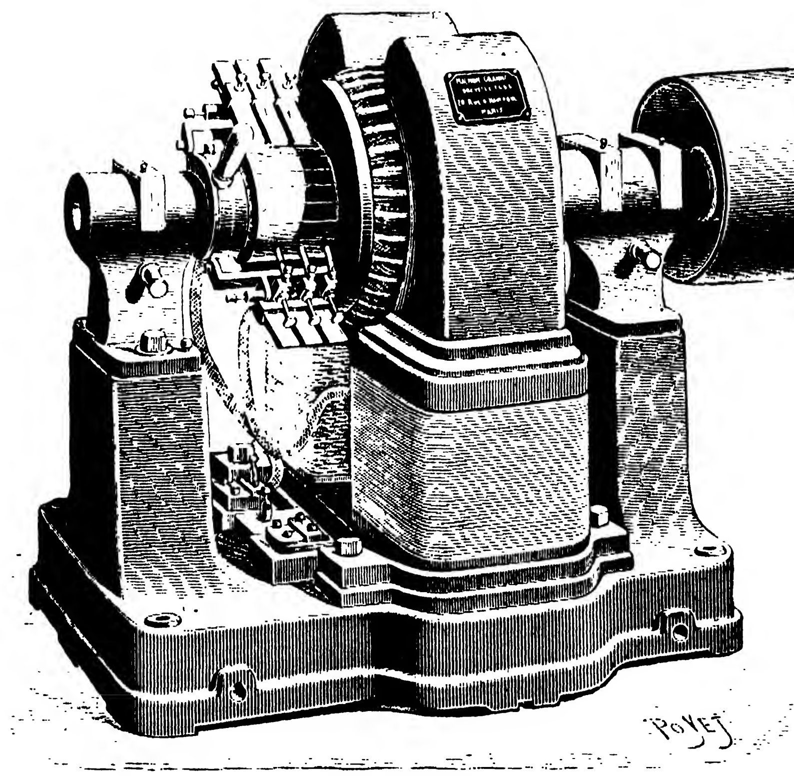


Fig. 282.—Overtype Dynamo

the other, the conductors need only be of sufficient size to carry one-half of the total current generated. There are, however, limits to the use of bipolar machines, which

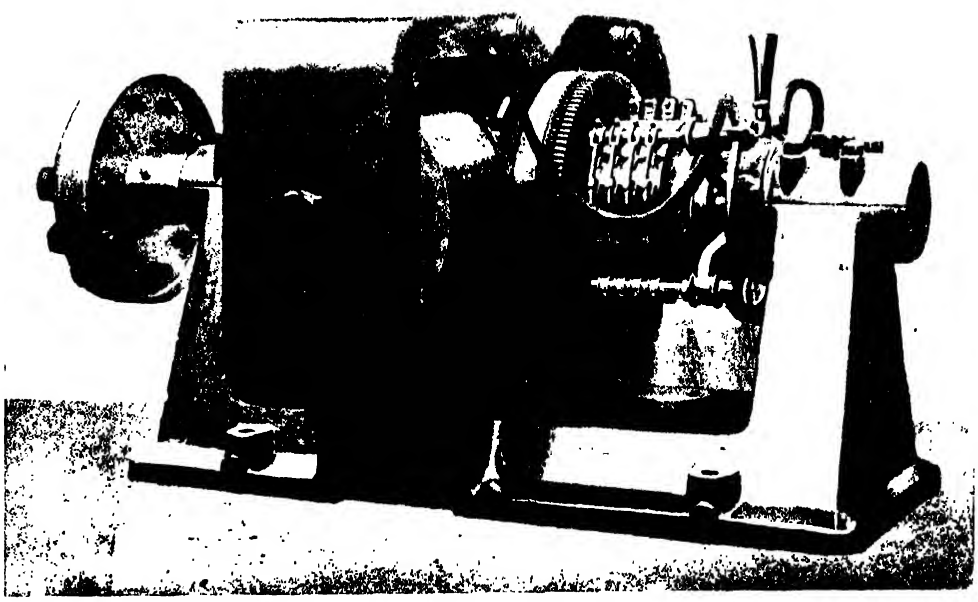


Fig. 283.—Ironclad Dynamo

are unnecessarily large when the voltage and power are considerable. In a bipolar machine the voltage is proportional to the revolutions, the strength of the magnetic field, and the number of conductors around the armature, and by increasing any one of these

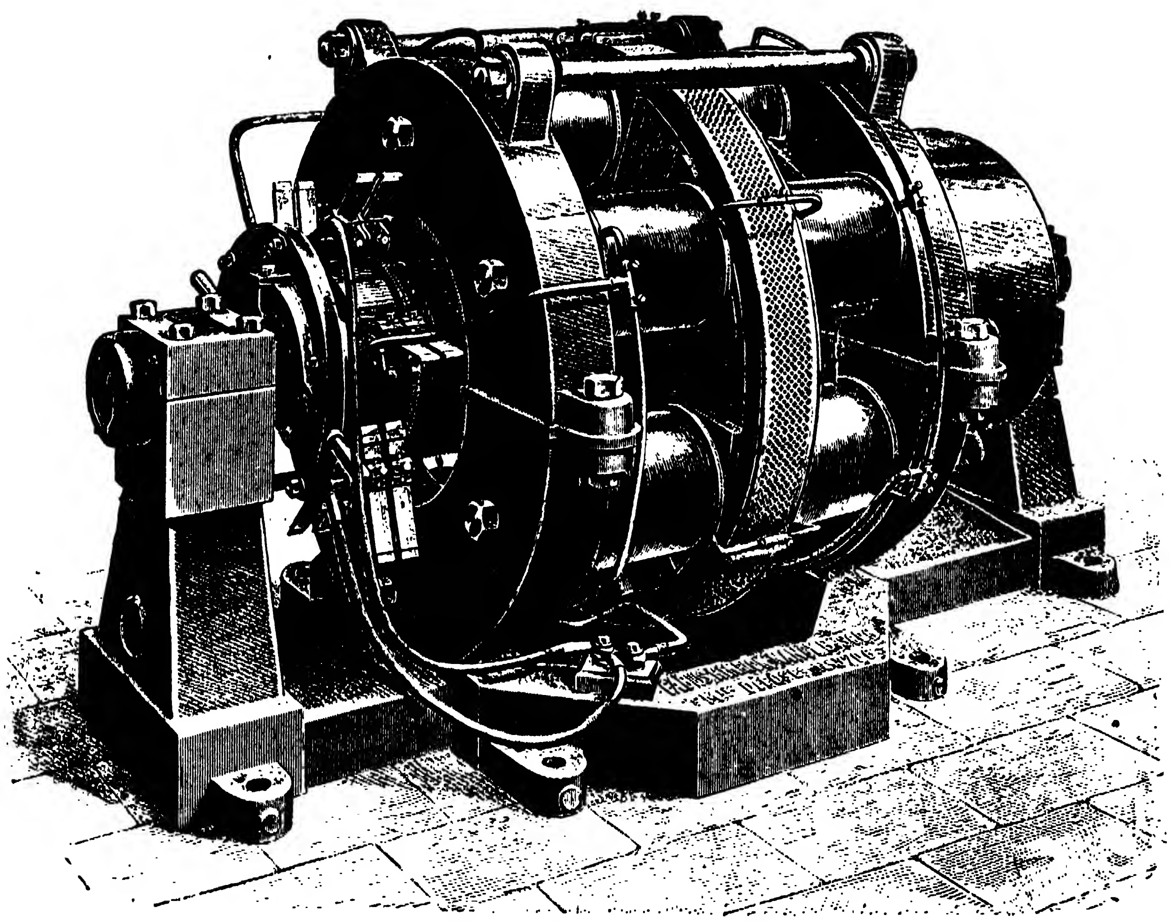


Fig. 284.—Early Form of Schuckert Disc Machine

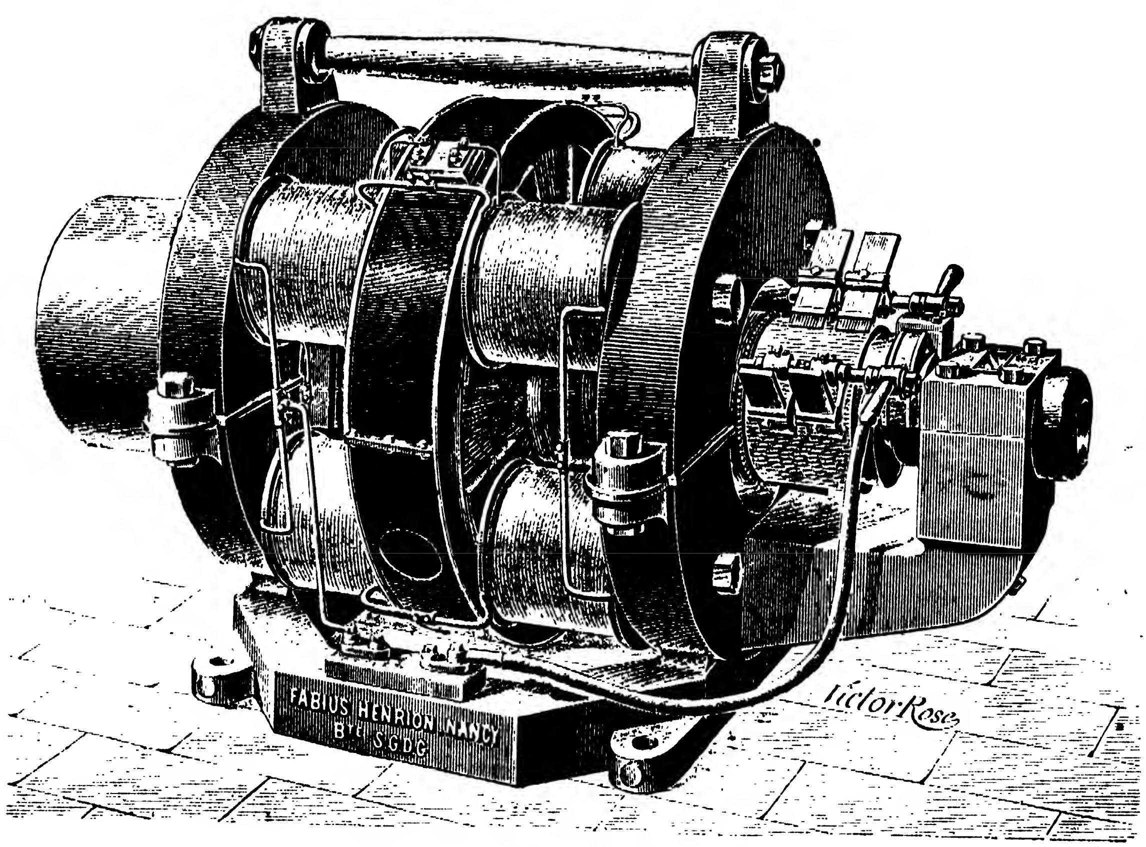


Fig. 285.—Early Form of Schuckert Disc Machine

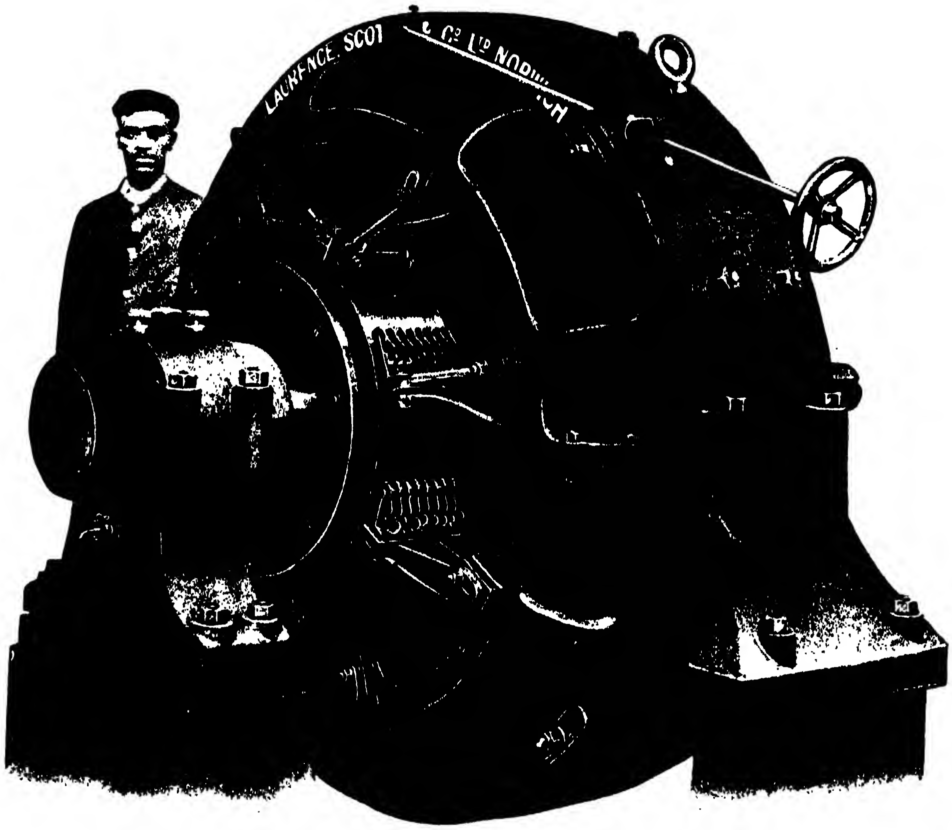


Fig. 286.—430 K.W. Standard Traction and Lighting Generator

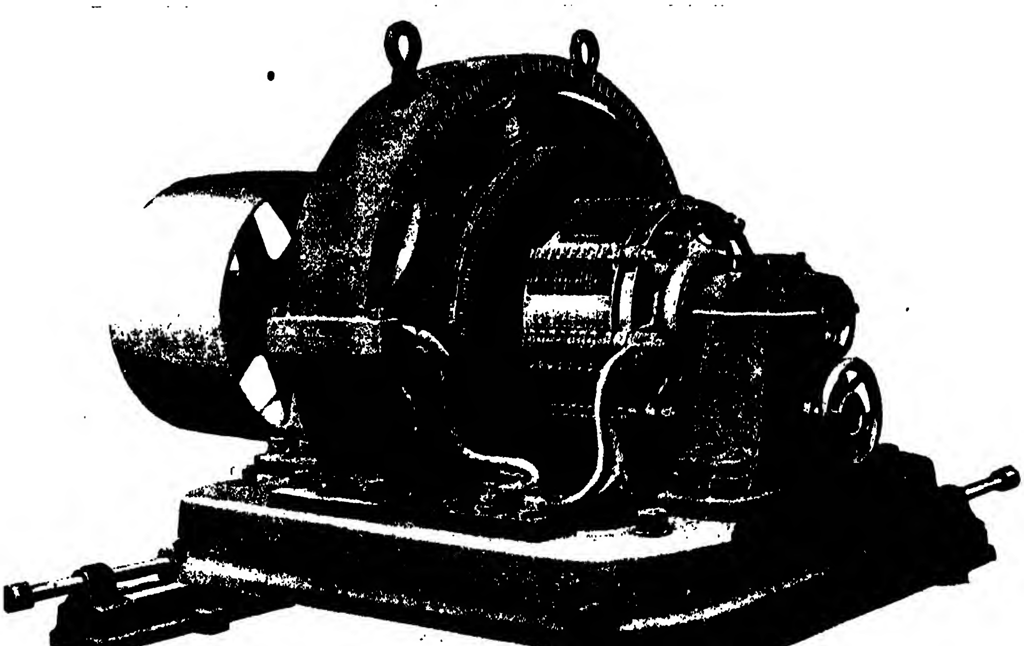


Fig. 287.—Eight-pole Generator by The General Electric Co.

the voltage is correspondingly increased, but the size and weight of the machine also becomes considerably greater for the same speed. Without increasing to any serious extent the size of the armature, the voltage may be doubled by adding a second pair of magnet poles, and thus doubling the total number of magnetic lines cut by the conductors each revolution, provided the number of paths through the armature are not altered, namely, two, as in the bipolar machine. For still higher voltage, multipolar machines, having three or more pairs of magnet poles, are generally used. Sometimes, however, the machine is required to generate a large current at a moderate voltage.

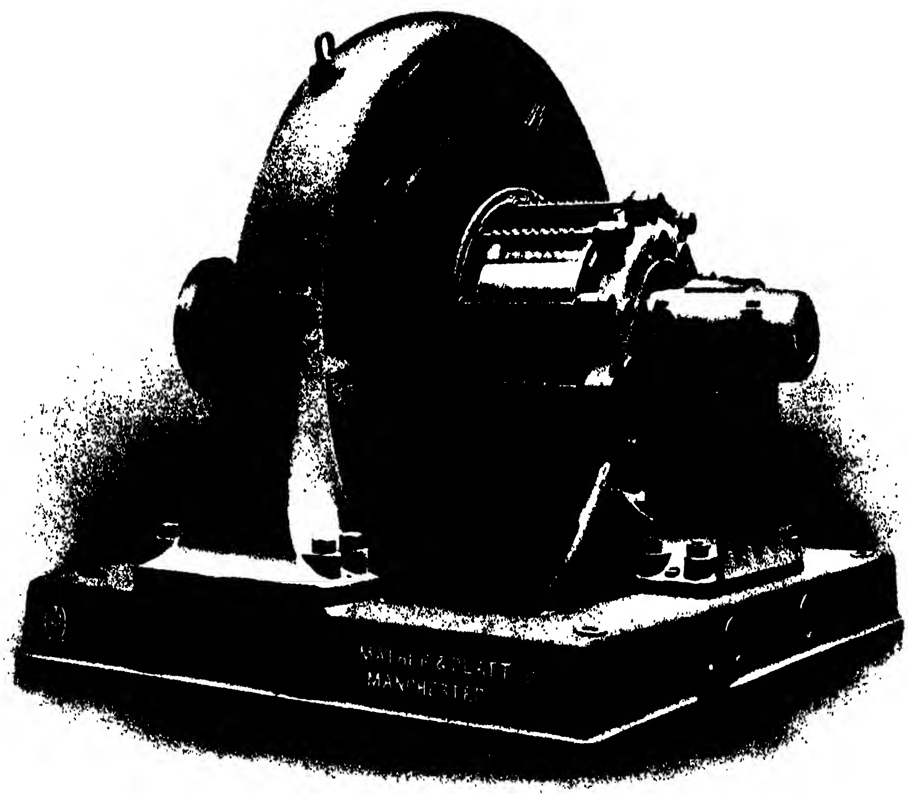


Fig. 288.—Multipolar Dynamo for Direct Coupling

This would involve, in the case of a bipolar machine, very heavy conductors, and therefore a large size of armature, and a correspondingly bulky dynamo. By adding a second pair of poles, and arranging the winding of the armature so that there are two paths corresponding to each of the magnet pairs, the conductors will have only to carry one-quarter of the total current. Compared, therefore, with a similar bipolar machine the four-pole machine will generate twice the current but at the same voltage. A multipolar machine with its armature arranged in parallel coils as above, will in the same way give a greater current in proportion to the number of its pairs of poles. It should be noted that a pair of brushes is necessary for each element, but all the positive brushes may be connected together, and similarly all the negative.

In the multipolar machine developing a correspondingly high voltage the armature

is wound in series, that is, there are only the two paths through the armature as in the bipolar machine, and only one pair of brushes is required. Several typical designs of bipolar machines are indicated in the sketches. They may have either ring- or drum-wound armatures. Fig. 276 is of a type introduced by Siemens and Halske of Berlin, and known as the overtype, while fig. 277 shows the inverted arrangement used by Edison. A single-coil dynamo, commonly called the C type from the similarity of its magnetic circuit to the letter C, is shown in fig. 278. Fig. 279 shows an arrangement which was at one time extensively used, and which is known as the Manchester type. It is essentially the C type doubled, giving a very solid and compact design. Ironclad dynamos illustrated in fig. 283 have the magnetic circuits completely encircling the

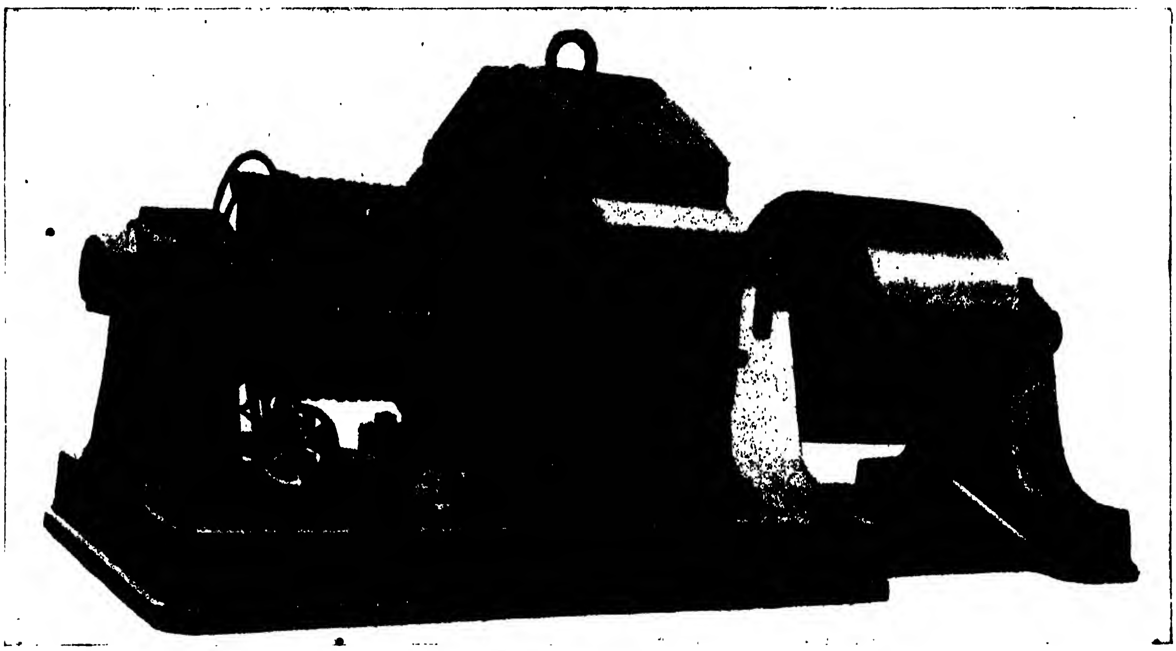


Fig. 289. - Six-pole Dynamo by Schneider & Co., of Le Creusot

machine. Owing to the leakage of the magnetic lines, which is often considerable, dynamos of this type are not now generally favoured.

Two diagrams are given to illustrate the use of two or more pairs of poles. In fig. 280, the pole pieces with their coils are shown bolted to the cast-steel framework which serves as a magnet yoke. The armature rotates within the curved pole shoes. It will be noticed that the adjacent poles are of opposite polarity, so that the magnetic flux has the smallest possible path through the armature core. Siemens and Halske, and others, have constructed machines in which this arrangement is inverted. In machines of this kind, known as internal-pole dynamos, fig. 281, the armature is stationary while the poles, together with the armature brushes, are rotated. Several examples are given of actual machines designed upon these various systems.

Fig. 282 illustrates the overtype dynamo.

Fig. 283 shows the ironclad type of dynamo, which is now rarely used.

Figs. 284 and 285 show variations of a type introduced by Schuckert and much favoured for a considerable time on the Continent. The armature is of

the disc type with the pole pieces facing both sides. Owing to the comparatively expensive nature of the design, dynamos of this type are now never built.

In the illustrations, figs. 286, 287, and 288, several multipolar machines with six, eight, and ten poles are shown.

A six-pole machine by Schneider & Co., of Le Creusot, is shown in fig. 289. The large armature surface is required to carry the heavy current which this particular machine is designed to produce.

ALTERNATING-CURRENT GENERATORS

When a current is transmitted along a wire, as, for example, when the current supplied by the generators is carried to distant motors, a certain proportion of the power is wasted in heating the transmission cables. The power lost is equal to the square of the current multiplied by the resistance of the live wires, that is, watts lost = C^2 R. To reduce this loss the live resistance R might be decreased by increasing the section of the copper wire if the price of copper were not prohibitive. The remaining alternative is to decrease the quantity of the current C, and to do this without reducing the power transmitted the voltage must be correspondingly increased, since the power in watts = voltage × current. In practice it is quite customary to generate the current at a pressure of 6000 or even 10,000 volts for transmission over a distance to sub-stations, where the pressure is lowered to suit the motors, lamps, or other plant to be driven. In a continuous-current dynamo the total pressure is distributed over a number of the armature conductors, and therefore between adjacent conductors and armature segments there are certain differences of potential necessitating careful insulation when the total voltage is considerable. For such high voltages alternators are used, as it is easier to design them to overcome these objections, and to dispense with troublesome and expensive commutators. At the terminals of a continuous-current machine the current flows steadily in the same direction, and this is due, as already explained, to the use of the commutator. When a commutator is not used the current flows alternately in opposite directions, and fluctuates continually from a positive maximum value through zero to a negative maximum, as has been already explained when describing the simple magneto. Fig. 290 shows diagrammatically the arrangement of the field and armature

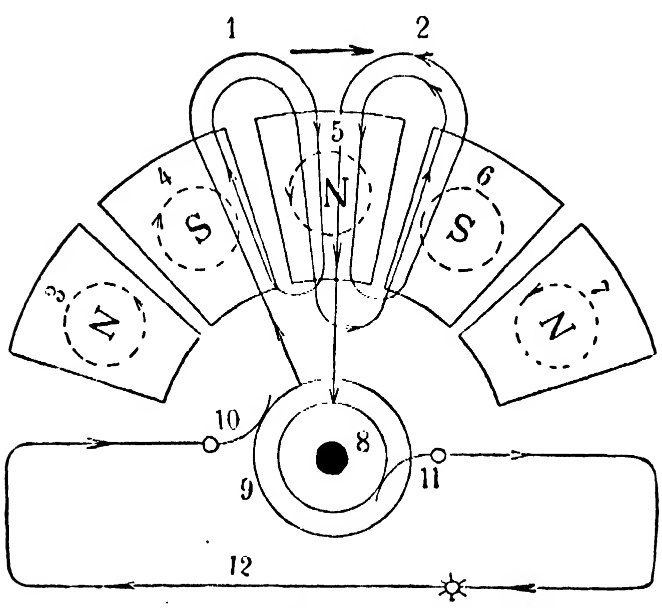


Fig. 290.—Currents induced in Alternator Armature Coil

CONTINUOUS-CURRENT MOTOR

INDEX TO THE PRINCIPAL PARTS

1. Left Bearing Shield.
2. Right Bearing Shield
3. Bearing Casing.
4. Bearing-bush Sleeve.
5. Bearing Bush.
6. Oil Ring.
7. Screwed Set Pin.
8. Oil Inlet.
9. Oil Reservoir.
10. Oil-drain Outlet
11. Motor Frame.
12. Line and Armature Connections.
13. Field Connection.
14. Pulley.
15. Armature Spindle.
16. Field Coils.
17. Armature Winding.
18. Armature Carcass.
19. Commutator.
20. Carbon-brush Holders.
21. Carbon Brushes.
22. Brush Spindles.
23. Brush-rocking Gear.
24. Positioning Flange.
25. Clamping-flange Ring.
26. Fixing-down Bolts.
27. Pole-shoe Ring.
28. Field-magnet Poles.

Model prepared from drawings kindly supplied by Messrs. Bruce, Peebles, & Co., Edinburgh.)

coils, and the directions of the induced currents. In this particular case the field-magnet poles are arranged around the shaft 8. Several of these, 3, 4, 5, 6, 7, are indicated, the remainder being omitted for clearness. By suitably winding the magnet coils each pole shoe acquires a polarity opposite to that of the adjacent pole, so that the armature coils 1, 2 in passing from 4 to 5 have the direction of their induced current reversed. Those parts of the coil cutting the field of the south pole 4 have the current flowing away from the shaft in the diagram, while in the parts of the coil cutting the north pole 5 the flow is in the opposite direction when the rotation of the coil is clockwise as indicated. From the arrows on the conductors it will be seen that the direction of the flow is from the ring 9 through the coils to the ring 8. Contact brushes 10 and 11, rubbing on these slip rings, allow the current generated to flow in the external circuit.

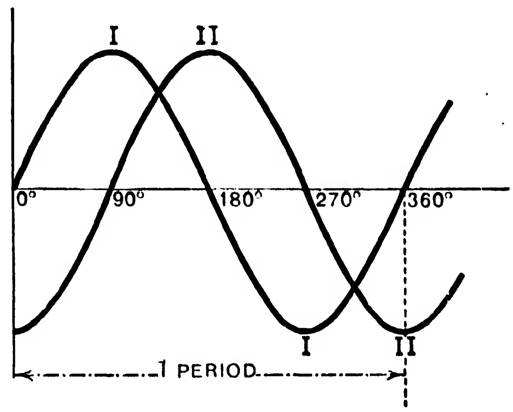


Fig. 291.—Fluctuation of Currents in Two Alternating Armature Coils

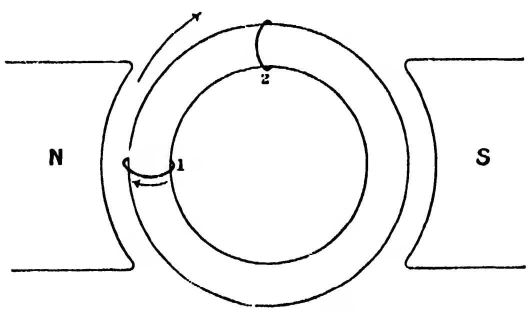


Fig. 292.—Diagram of Bi-phase Alternator

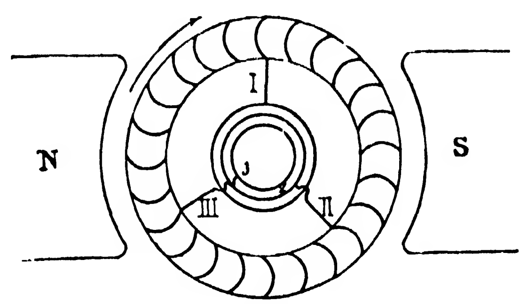


Fig. 293.—Diagram of Three-phase Alternator

In crossing from side to side of one pole the current increases from zero to a maximum and then falls to zero, then when crossing the succeeding pole of opposite polarity the

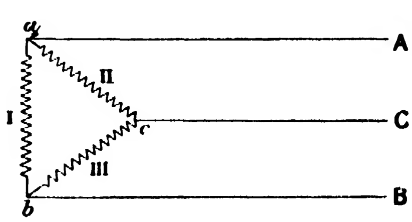


Fig. 294.—Three-phase Mesh or Delta Connection of Coils

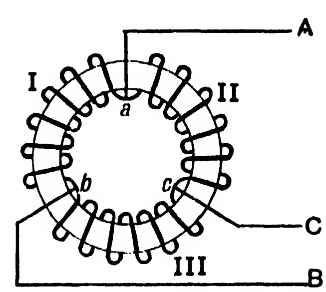


Fig. 295.—Mesh-connected Armature Coils

current again increases to a maximum and falls to zero, but the flow is in the opposite direction, that is, for each pair of poles there is one reversal, and therefore if eight poles are arranged around the circumference there will be four reversals during each

revolution. Other coils similarly arranged over the remaining poles would in the same way send currents through the rings 8 and 9 to the external circuit, and if the relative

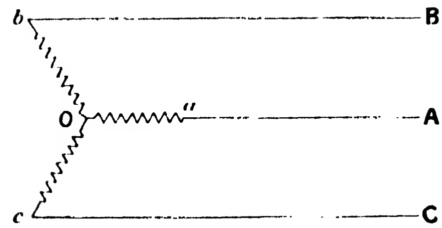


Fig. 296.—Three-phase Star or Y Connection of Coils

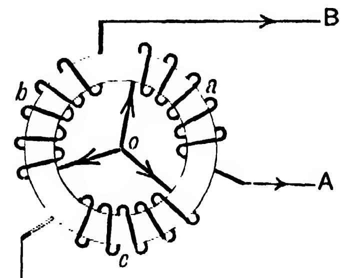


Fig. 297.—Star-connected Armature Coils

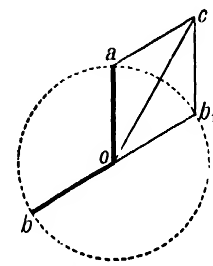


Fig. 298.—Three-phase Diagram

positions were identical the induced currents would be all of the same value at the same instant, that is, they would rise and fall together and be of the same phase. A

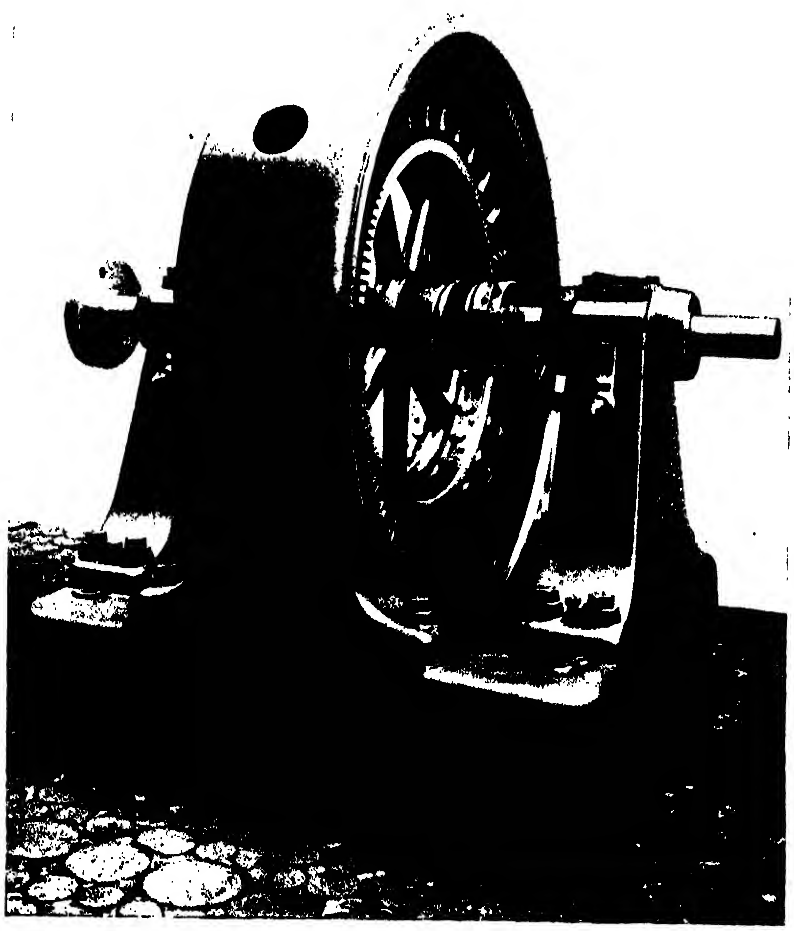


Fig. 299.—Three-phase Generator, 105 H.P.

current of the kind just described is known as single phase. It is possible, if desired, to connect the coils in series as already explained in the case of the continuous-current

dynamo. Suppose now a second series of coils is arranged in advance of the first set, and entirely separate from it, so that when the one current is at a maximum the current in the second set is at zero. Fig. 291, which explains the action diagrammatically, shows the variations in the voltages as the coils pass over the pairs of poles. Curve I shows the variation in the first set and curve II in the second. At position 0°, when curve I has a zero value curve II has a negative maximum. At 90°, current I has risen to its positive maximum and II has become zero, and so on. The two curves are

Fig. 300.—Rotary Field Magnets of Alternator, by Siemens Bros.

displaced as it were by quarter of a complete cycle or period. Alternators arranged in this way are called two-phase or bi-phase.

Similarly, when three separate sets of coils are arranged separated by one-third of the distance between similar poles, the alternator is said to be tri-phase, or polyphase when three or more than three sets of coils are used.

Each complete cycle of the current is called a *period*, that is, for each period the current passes from one value through all the intermediate positive and negative stages to the same value. The number of periods per second is called the *periodicity* or *frequency*, usually symbolized by the letter n. As already explained, the periodicity of a machine depends not only upon the number of revolutions per second, but also

upon the number of pairs of north and south poles; for example, the periodicity for a two-pole machine (one pair) equals the number of revolutions R per second, that is, $n = R$; while for an eight-pole (four pairs) machine $n = 4R$. When the frequency approaches 80, alternating currents can be used for lighting as well as traction, since the fluctuations are so rapid as to be unnoticeable. The term phase is used to denote the condition of the current at any moment, for example, one current differs in phase from another when they pass through corresponding values at different instants. In

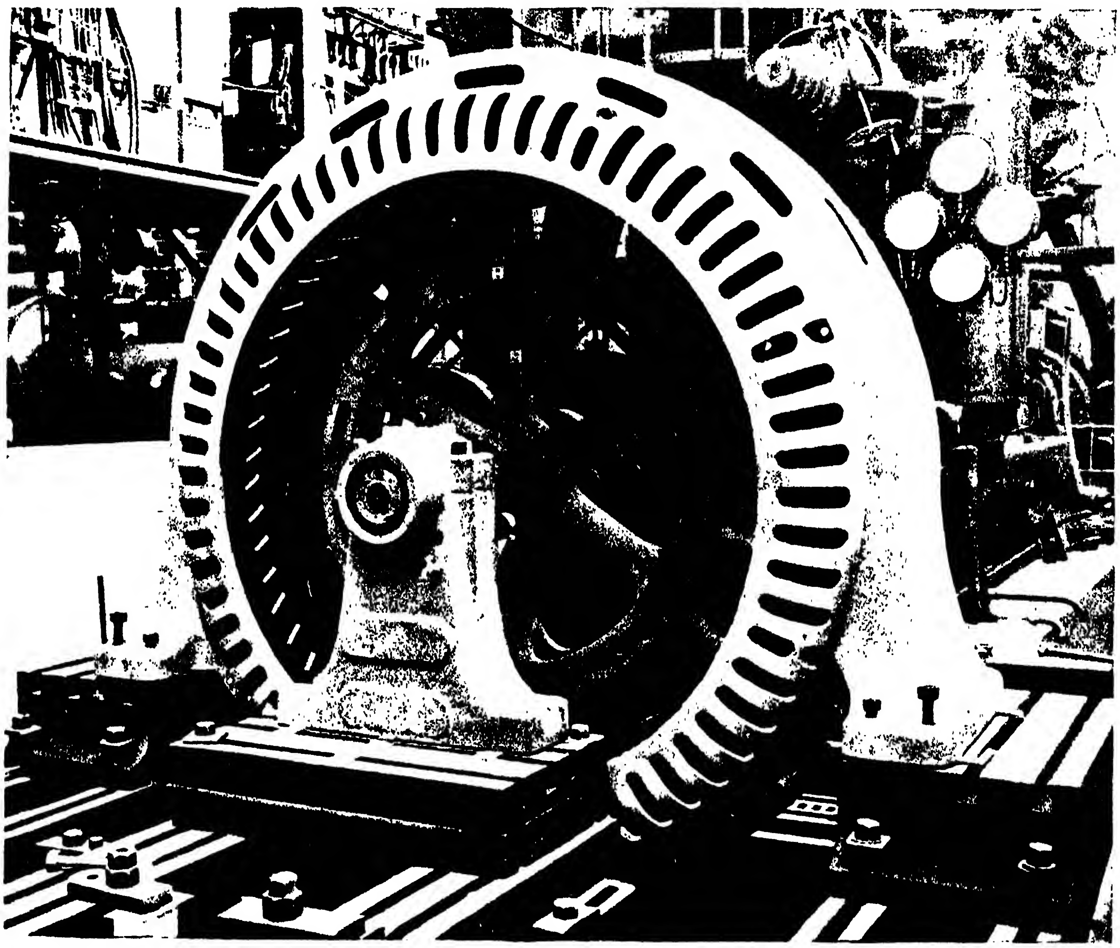


Fig. 301.—Alternator showing Arrangement of Rotating Field Magnets and Stationary Armature

a bi-phase alternator the two currents pass through the same condition at an interval of quarter of the period. Fig. 292 shows diagrammatically the essential parts of a bi phase alternator. Magnetic lines of force are generated by a continuous current circulating around the field magnets, and flow from north to south through the armature ring core. Suppose two armature coils 1 and 2, or, for simplicity, two rings of wire, are arranged on the armature in the relative positions indicated, then as the armature rotates the currents generated will differ in phase by one quadrant. To collect these bi-phase currents it is only necessary to connect the ends of each coil to separate pairs of continuous slip rings upon which the four brushes bear. From the machine four separate lines will therefore pass to the outside circuits. Three-phase currents may be similarly obtained if the two coils are replaced by three coils arranged at equal

distances around the armature ring. It is sufficient, as shown in fig. 293, to make the ring coils continuous and to take tappings from positions 120° apart to three slip rings upon which the brushes bear and from which the live wires carry the current, each wire carrying one of the three phases.

Whether for two-phase or three-phase alternators the armature coils may be grouped in either of two ways called mesh or star connection or in a combination of these.

Fig. 294 shows the mesh arrangement for a three-phase armature, while fig. 295 shows the same winding in place upon the armature ring. The three separate windings I, II, and III form a continuous coil with the lines *a*, A, *b*, B, *c*, C connected to equi-

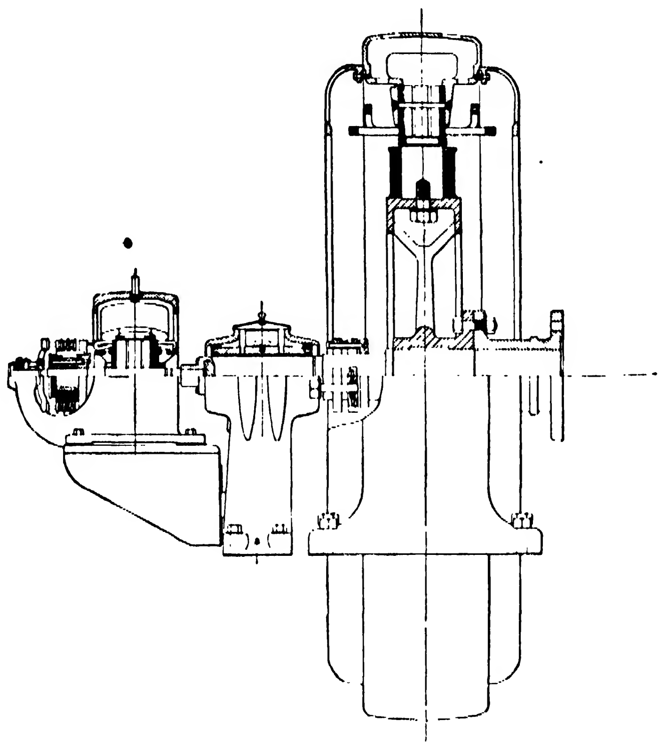


Fig. 302. Section of Siemens Alternator with Continuous-current Field Exciter

distant points. When the coils form a closed mesh in this way they are said to be *delta* connected. The star arrangement is similarly illustrated in figs. 296 and 297. Here the ends of the three coils *a*, *b*, *c* are connected together at O, while from the free ends the live wires pass as before. Coils joined together in this way are said to be **Y** connected.

In the mesh arrangement the voltage between any pair of live wires is simply the voltage generated in the coil between them. This, however, does not hold for the delta arrangement, as may be seen from consideration of figs. 296 and 298. Between A and B the difference of voltage is determined by the coils O, *a* and O, *b* which generate currents differing in phase by 120°. The voltage between the lines will be the resultant of these two. To find this resultant from a point O, fig. 298, draw O, *a* to represent in direction and value the voltage in the coil O, *a*, and draw O, *b* to represent the similar values for the coil O, *b*, then the resultant O, *c* = *a*, *b* represents the

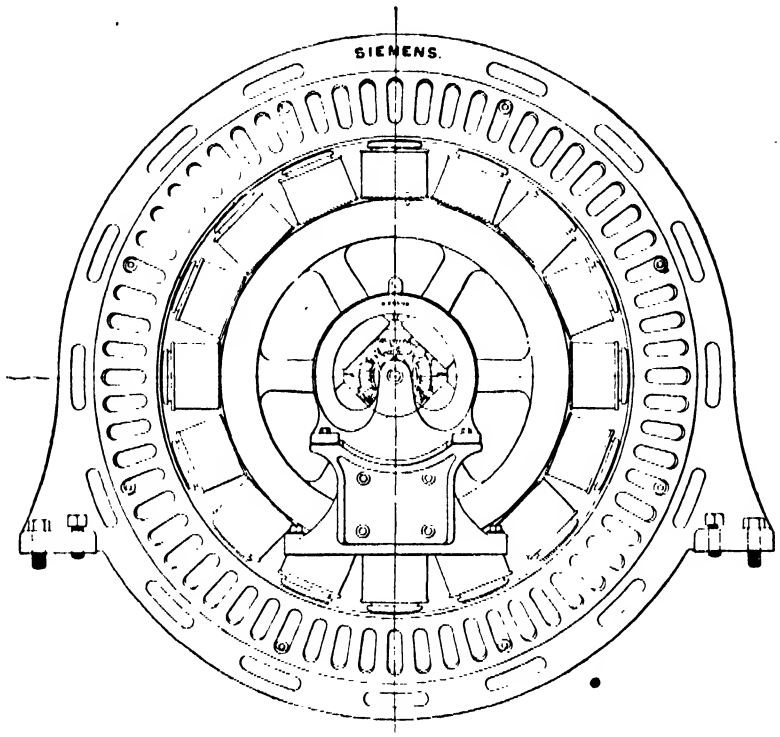


Fig. 303.– Siemens Alternator with Continuous-current Field-exciting Dynamo

voltage between the lines; thus for phases separated each by one-third period, that is, 120°, the resultant shown equals E $\sqrt{3}$ = (1.732 E) where E is the value for each of the coils. Alternators may be constructed with the poles fixed and the armature rotating within them as shown in the illustration (fig. 299) of a three-phase machine. In this case the three armature circuits are connected to three insulated slip rings upon which the brushes rest. Continuous current must be supplied to the magnet coils, since the magnetic fields must always have a constant direction, and this involves the use of either a separate continuous dynamo generally called an exciter, or of some means of rectifying a portion of the alternating currents developed by the main machine. Instead of having the magnet coils fixed, the armature may be the stationary portion while the magnetic fields are rotated as shown in the illustrations (figs. 300, 301, 302, 303). The continuous current is supplied by two slip rings to the magnet coils, while the three wires of the external circuit are connected directly to the three windings of the stationary armature. For large alternators this arrangement is very convenient and is most frequently adopted. The armature itself,

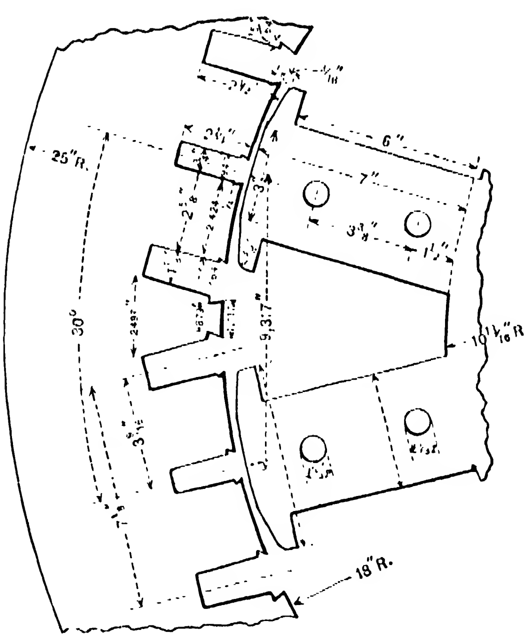


Fig. 304.—Armature and Field Laminations, with Slots for Armature Coils

which thus forms the frame of the machine, is made in large units for convenience in two parts bolted together; smaller machines usually have the frame in one piece. On the inner face slots are provided to take the armature coils, which are composed of copper strip bent into coils of suitable form and turns. If the metal core in which the coils are placed were solid there would be a considerable loss of power, due to molecular displace-

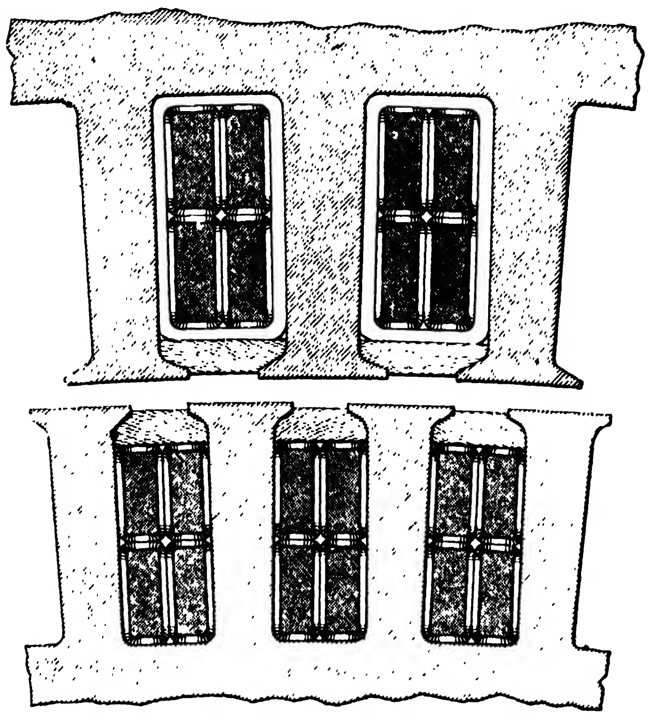


Fig. 305.—Core Laminations with Coils in Position

ment in the metal as the currents fluctuated, and to eddy currents. It is customary therefore not only in alternators, but also in continuous current dynamos, to make the metal core of layers of sheet iron placed on edge. Holes are punched in the edges of these sheets so as to form, when assembled, continuous slots across the face of the laminations into which the bars of the armature coils are laid. This is clearly indicated in the

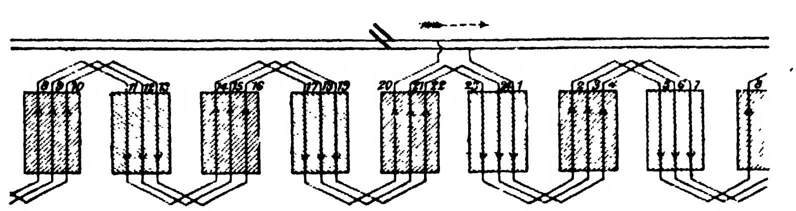


Fig. 306.—Single-phase Wave Winding

illustrations (figs. 304 and 305). Two methods of winding the armature may be adopted. They are called wave or lap winding according as the winding is carried forward continuously from pole to pole or laps back upon itself. The figures 306 and 307 show developed views of the two methods as applied to single-phase alternators. It will be seen that in both cases any conductor passing across a pole face is connected to one that crosses a pole of opposite polarity in the opposite direction. Alternate

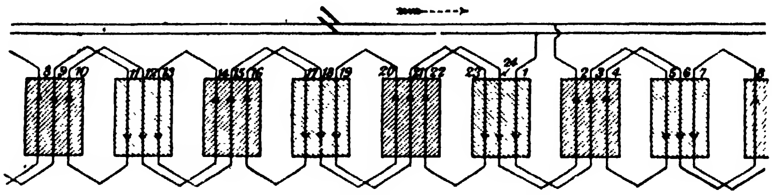


Fig. 307.—Single-phase Lap Winding

poles are of opposite polarity, as in continuous-current multipolar machines. A three-phase wave winding is illustrated in fig. 308, and a corresponding lap winding in fig. 309.

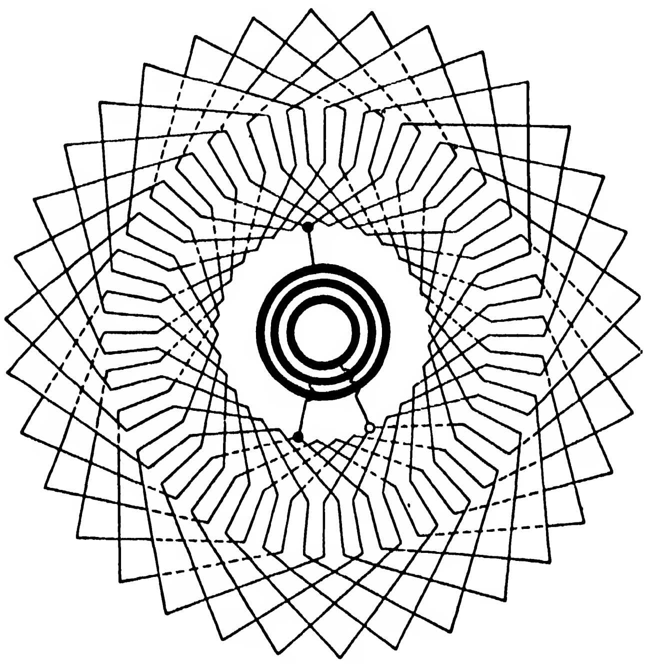


Fig. 308.—Three-phase Wave Winding

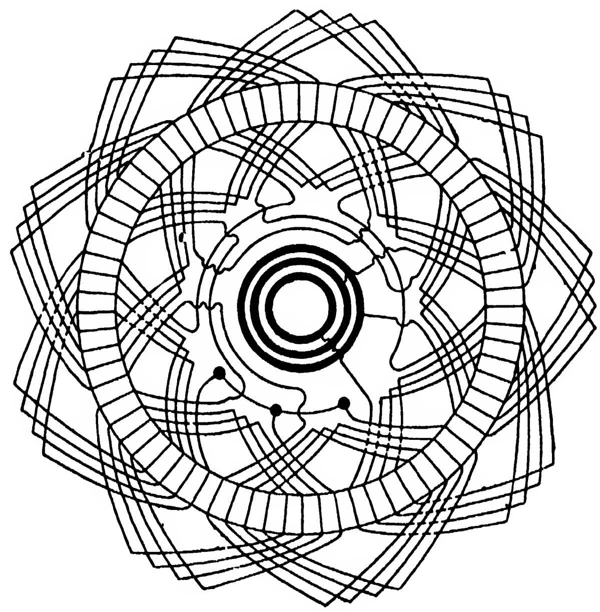


Fig. 309.—Three-phase Lap Winding

Induction alternators have no coils that rotate, thus dispensing with both armature and field slip rings. The rotating portion on the spindle consists of a mass of iron or steel with projections serving as poles. Around the periphery of this rotor is placed

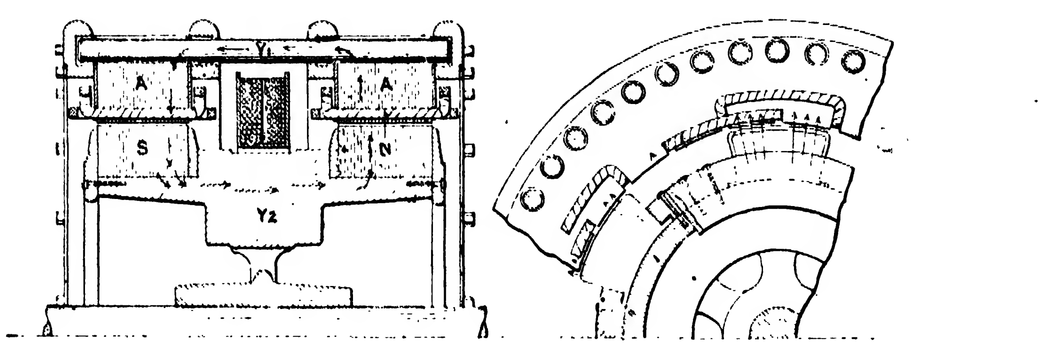


Fig. 310.—Two-phase Inductor Alternator

a stationary magnetizing coil in which, as before, a continuous current circulates, and the armature coils are placed on either side. This is shown in the diagrammatic sketch, fig. 310. From the section given it will be evident that the magnetizing coil

will produce a magnetic flow as indicated by the arrow through the armature coil core and through the iron of the rotor. Each time the projections on the rotor come opposite a pair of armature coils a path is provided for the flow of the magnetic lines induced by the stationary magnet coil. In practice the projections are laminated to prevent the formation of waste currents in the iron of the cores. A three-phase induction motor is illustrated in fig. 311.

Electric Motors. Continuous-current dynamos may, with the addition of a suitable starting switch, be made to serve as motors,

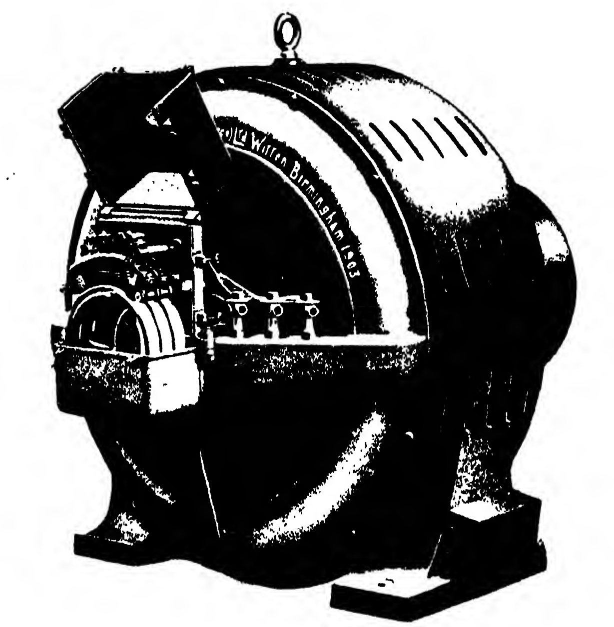


Fig. 311.—"Witton" Three-phase Induction Motor

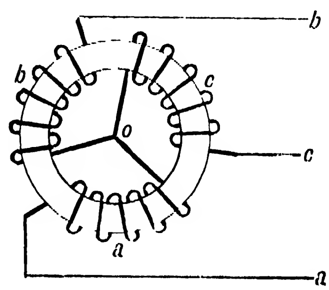


Fig. 312.—Diagram of Three-phase Star Winding

receiving the current from a generator and converting it into rotary motion. To some extent an alternating-current generator may also be used as a motor, but the action is more complex and requires some further consideration.

Rotating Magnetio Fields. A very close analogy exists between the mechanical

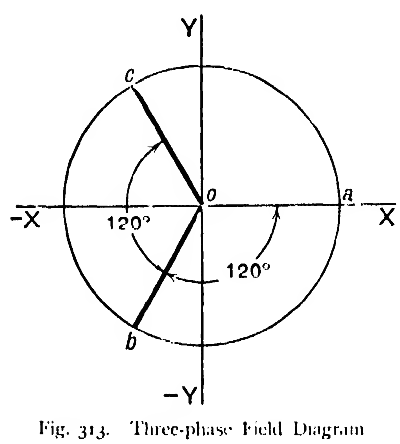


Fig. 313.—Three-phase Field Diagram

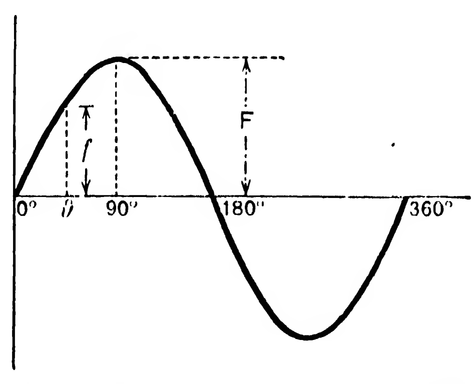


Fig. 314.—Diagram of Voltage Variation in Field Coil

arrangement of three reciprocating pistons acting upon a common crank, as in the Brotherhood engine, already described in the article upon the steam engine, and between the arrangement of three coils, spaced 120° apart, in which currents differing in phase by one-third period circulate. Fig. 312 shows such an arrangement, and fig. 313 is a

diagram of the field intensities at any particular moment, from which the corresponding resultant magnetic field may be determined by resolving the values of each of the three fields into components along two axes O X and O Y and then finding the resultant.

Coil *a* in fig. 312 will produce a horizontal magnetic flow, and its direction may be represented by a line O *a* in fig. 313. Since the current, and therefore induced magnetism, fluctuates in the way represented by the curve in fig. 314, and since this curve may be taken as a sine curve, or more generally as a combination of sine curves, the value of the magnetic field at any instant may be taken as F sin θ, where F is the maximum intensity and θ is the angle of the phase. O, *a*, therefore, resolved along the axis O X is at any position of phase equal + F sin θ, and zero along O Y. Coil *b* induces magnetism along the direction O, *b*, and since the current in coil *b* differs in phase from that in *a* by 120°, its value = F sin (θ — 120°), and its components along O X and O Y respectively are — F sin (θ — 120°) cos 60, and — F sin (θ — 120°) cos 30°. Similarly the field induced by coil *c* is representable by the line O, *c*, and has a value F sin (θ — 240°), since it differs in phase from the first field by two-thirds period, that is, $\frac{2}{3} \times 360° = 240°$.

Its components along the axis are — F sin (θ — 240°) cos 60, and + F sin (θ — 240°) cos 30.

Adding the values along the axis O X the resultant is = F sin θ — F sin (θ — 120°) cos 60° — F sin (θ — 240) cos 60° = $\frac{3}{2}$ F sin θ = X.

Similarly the components along the axis of Y = F sin (θ — 240°) cos 30° — F sin (θ — 120°) cos 30° = $\frac{3}{2}$ F cos θ = Y.

If R = resultant = $\sqrt{X^2 + Y^2} = \frac{3}{2}\sqrt{F^2(\sin^2\theta + \cos^2\theta)} = \frac{3}{2}$ F, and in direction is as shown by the line O R, making an angle θ with the axis of Y; since the component of R along O Y must equal $\frac{3}{2}$ F cos θ = R cos θ.

Since θ increases uniformly with time throughout each period, it follows that not only is the resultant field produced by the three-phase alternating currents constant, being equal to $\frac{3}{2}$ the maximum value of any one of the fields, but also the resultant field rotates with a constant angular velocity.

By a similar method of reasoning it may be shown that for polyphase currents, say, for *n* phases circulating in coils symmetrically grouped, the resultant field will be equal to $\frac{n}{2}$ (value of field produced by one phase). For two-phase alternators the resultant field = $\frac{2}{2}$ = 1, that is, the resultant field has a constant value equal to the maximum field of either of the phases.

Before describing the way in which these rotating magnetic fields are employed in motors, it is necessary first to explain the action of synchronous motors, so called from the fact that the speed of rotation must agree with the frequency of the alternating current supplied if the motor is to run continuously.

Instead of rotating the simple armature illustrated in fig. 315 between the constant poles of an electromagnet, as was previously done to produce an alternating single-phase current, suppose that this current is applied to the armature as indicated by the arrows while a continuous current flows through the magnet coils. During one phase of the alternating current the armature will tend to rotate in one direction, but owing to its

inertia the current will be in the opposite phase before any rotation takes place, that is, the inertia of the armature is too great to respond quickly enough to the rapid changes of the field reaction. If, however, the armature could reach the vertical position before the change took place it would then tend to rotate in one direction. By rotating the armature mechanically until its rotation synchronizes with the fluctuations of the alternating current, the armature will then continue to rotate unassisted and against an external load.

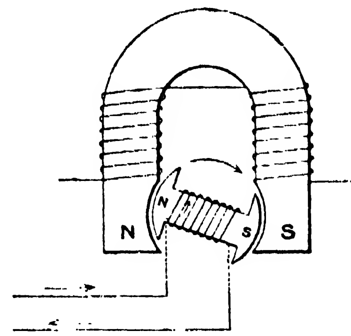
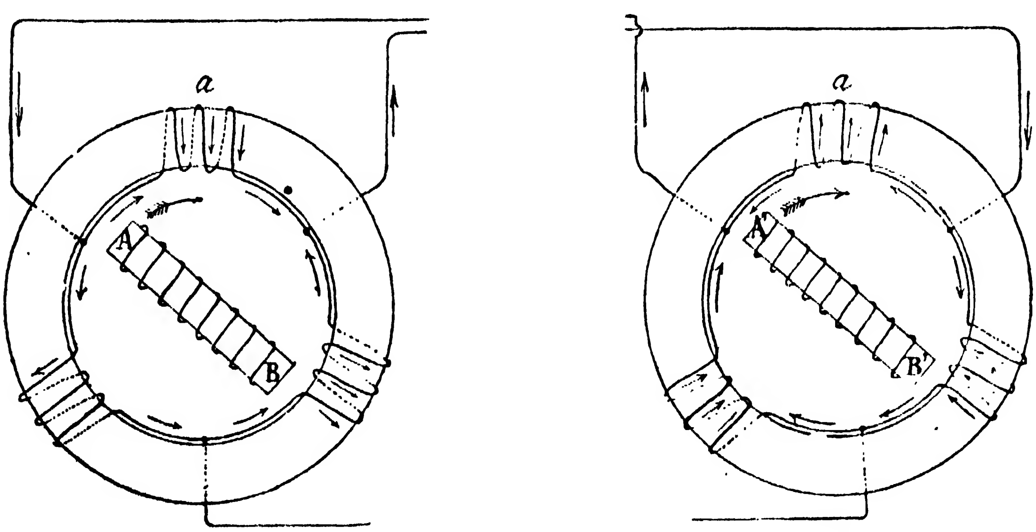


Fig. 315.—Diagram of Single-phase Alternator with Rotating Armature

A great disadvantage of the **single-phase synchronous motor** is that it is not self-starting, though special arrangements have been devised for making it so. It must be first rotated mechanically or electrically by means of a separate continuous current winding until a speed is reached which corresponds with the frequency of the current and the number of poles on the motor. When the synchronous speed is reached the load can then be gradually applied. There is the further disadvantage common to all these synchronous machines, whether using single or polyphase currents, that the field must be excited with continuous current from some separate machine or special armature winding.

Currents of two or more phases circulating in coils wound upon an armature produce rotating magnetic fields which may be utilized to obtain the desired self-starting property.



(1) (2)

Fig 316.—Diagram of Three-phase Alternator connected to Three phase Synchronous Motor Stationary Armature

When three-phase currents are used, the rotating field is stronger than with the two-phase, and there is a better starting torque, otherwise the principles involved are the same, so that it will be sufficient if the action of a three-phase synchronous motor alone is described. In fig. 316, *a* is the armature upon which the three coils are wound, the direction of the winding being the same throughout as already explained. Each of the three live wires shown connected to the coils serves to carry to the motor a current

which differs in phase from the others by 120°. Within the armature the field magnet A, B is rotated mechanically, so that its magnetic field induced by the continuous current circulating in its winding cuts the armature coils consecutively, and induces in them the three currents of different phase. This armature and field constitute the alternating-current generator. An exactly similar arrangement of parts serves as the motor. When corresponding live wires of both are connected together, and continuous current is supplied to both field magnets, a magnetic field is established which sweeps uniformly around the armature and reacts upon the constant magnet field. Arrows placed on the coils in the figure denote the directions of the flow. Since the flow in the motor armature coils is opposite to that in the generator it follows from Lenz's law that the motor field magnet will tend to oppose this, and that it will therefore rotate in the same direction

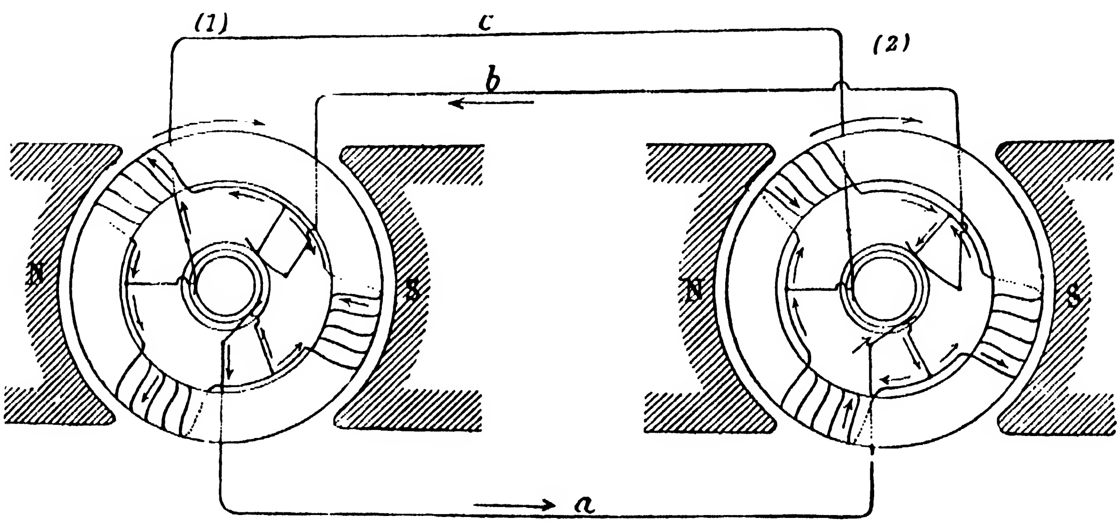


Fig. 317.—Three-phase Alternator and Motor with Stationary Fields

as the generator. Though the motor is self-starting it has not at first a sufficient starting torque to carry any load. The load can only be carried when the motor has reached its synchronous speed. Continuous current for exciting the field magnet may be derived in various ways; in some cases from a small supplementary continuous-current generator, or from special coils and a commutator on the motor itself. Fig. 317 shows the same arrangement of three-phase generator and motor, but in this case the field is stationary while the armature revolves, three sets of slip rings and brushes being supplied to carry the three-phase currents instead of, as before, only two to carry the field-magnet continuous current.

Synchronous polyphase motors have the advantage over single-phase motors which cannot make use of rotating magnetic fields in that they are self-starting, but they do not start when the motor is loaded. This difficulty is overcome in asynchronous, as they are usually called, induction motors which dispense with the field magnet and continuous-current coils. The rotating portion has currents induced in it by the rotating field of the stationary portion which carries the phase windings. These induced currents set up a magnetic field which reacts on the rotating magnetic field, and so produces the turning motion. If in an ordinary continuous-current dynamo the armature circuit

is completed and the field magnets are excited, a resistance will be felt when it is attempted to rotate the armature by hand, the reason being that as soon as the closed coil on the armature is made to cut the lines of the magnetic field a current is generated in it. This induced current gives rise to a magnetic field which reacts on the primary magnetic field and resists the rotation, that is, the movable portion tends to preserve its original position relatively to the field magnets. The converse, therefore, holds, namely, that if the field magnets are rotated the short-circuited armature would follow after it in virtue of the magnetic reactions of the primary and the induced magnetic fields. When polyphase currents are used in suitably arranged coils the resulting magnetic effect is the same as if the poles of a permanent magnet were uniformly rotated. Instead, therefore, of actually rotating a field magnet excited by means of continuous current, a similar effect may be obtained by the use of a rotating magnetic field acting upon a short-circuited armature. In speaking of induction motors the terms rotor and stator are used to denote the rotating and the stationary portions, since the terms armature and field magnet are not wholly applicable and lead to some confusion. Sometimes the stator is called the primary and the rotor the secondary portion. Most frequently the stator is the portion in which the phase coils are wound, and the rotor the self-contained mass in which the currents that react upon the rotating field are induced. This gives a more substantial form of machine, since there are no brushes or slip rings, and the fine wire coils, being stationary, are not subjected to centrifugal forces as they would be if the arrangement were reversed. There exist disadvantages of comparatively minor importance, in that the stator, having the larger diameter, involves a larger quantity of expensive material and the magnetic leakages are greater.

Considering again the case of a short-circuited armature rotated in a magnetic field, the resisting torque will increase the greater the relative motion of the field and closed coils, that is, the greater the rate of cutting of the magnetic lines by the coils. If the rotor moved at the same speed as the rotating magnetic field the rotor coils would not cut any magnetic lines, there would therefore be no induced currents and no torque. Only when the rotor lags behind is any torque exerted, and the greater the lagging the greater the torque. This difference in speed between the rotating magnetic field and the rotor, upon which the torque depends, is known as the slip of the motor. In large motors the slip is about 2 per cent at normal load, but in very small machines it may reach 10 per cent. From what has been said it will be evident that induction motors, besides being self-starting, have the great advantage of being able to start while under the load, and further, as the load is increased within certain limits, the slip of the rotor increases, and the motor torque adjusts itself to meet the increase of the demands upon it.

No feature of the stator calls for detailed description. Usually the sets of coils consist of insulated and suitably-formed copper strips inserted in the inner surface slots of the stator laminations, as in the case of the alternators already described. The rotor, on the other hand, requires some explanation. Originally it consisted simply of a copper cylinder, to which was added a soft-iron core to increase the magnetic properties. Currents induced in the copper sheathing were, at a later date, constrained to move in definite directions by slotting the copper. This suggested the present-day

development of copper bars inserted just beneath the surface of the soft laminated iron core. The copper bars are in many types joined at their ends by heavy continuous copper rings, giving the rotor an appearance which has suggested the generally-used name "Squirrel Cage" (fig. 318). The copper bars provide circuits of small resistance for the large induced currents, while the soft-iron core provides the best possible magnetic circuit.

Many arrangements of the copper bars may be adopted to suit special circumstances. Instead of being all placed in parallel, they may be grouped in sets or connected in series, and wound either according to the lap or the wave method. Some such arrangement is necessary to prevent an excessive flow of current when the motor is standing and the supply is switched on. Under normal load conditions the torque is directly proportional to the slip and inversely proportional to the rotor resistance. When the rotor, on the other hand, is about to start, the torque is directly proportional to the rotor resistance. By winding the rotor with three coils connected in the star fashion, and by inserting adjustable resistances in the circuits, the starting torque may be increased without increasing the flow of current. Fig. 319 shows a diagram of the connections, with the three rotor windings connected to slip rings on the shaft, and with suitable resistances in series. When the motor is stopped the resistances are all in circuit. As the motor speed increases the resistances are cut out, and when the normal speed is reached the whole winding is short-circuited by the insertion of a ring which connects the coil ends together. Unless starting resistances are used, the flow of current on starting may be from six to eight times the normal demand, and such a flow of current would in practice cause serious variations of voltage in the supply mains. A further advantage of the induction motor is, that when the rotor for any reason is made to rotate faster than the rotating magnetic field the action is reversed, that is, the rotor offers a resistance to the motion and generates currents which pass back into the supply mains, that is, the motor acts as a generator. For this reason induction motors are very suitable for traction work, since when the train or car commences to gather speed, as when descending an incline, the motors act as brakes, absorbing in a useful way the kinetic energy developed, and pumping it back into the mains.

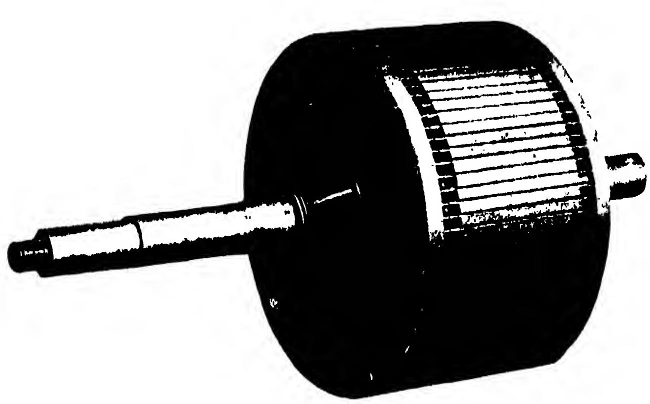


Fig. 318. Squirrel Cage Rotor of Induction Motor

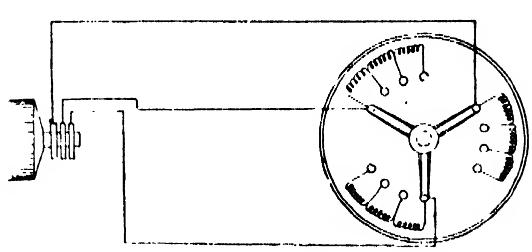


Fig. 319.—Starting Resistance for Induction Motor.

Polyphase currents are universally used when the energy requires to be transmitted

over a considerable distance, as, for example, in any traction installation. To reduce the cost of the copper cables necessary for the transmission of a definite power, the voltage must be increased in order to decrease the current to be carried. A usual voltage for transmission in practice is about 6000, but much higher voltages have been adopted for long-distance transmission. At this high voltage it is found necessary to dispense with such complications as commutators and to transmit the original alternating current. There are other advantages which determine the use of alternators, chiefly in the better insulation obtainable. In a traction installation the high-voltage currents are usually reduced in pressure at sub-stations near the place where the power is to be utilized. This is done by means of stationary or static converters, which consist simply of two superposed but entirely separated windings, one consisting of many turns of fine wire, in which the high-voltage small current flows, and the other consisting of fewer turns of heavier, in which the larger current at the lower voltage circulates. Only alternating currents can be transformed in this way, since the transformation results from the cutting of the secondary coils as the primary current rises and falls. There is thus the great advantage in the use of alternating current, in that its voltage may be transformed either down or up to a lower or a higher pressure without the use of any moving machine. In practice for, say, a tramway installation the voltage may be transformed in this way down to about 600 volts alternating. If the tramway motors are of a polyphase type the current may be supplied directly, but if continuous-current motors are used there must be a further transformation from alternating to continuous to make the current suitable. This is generally effected by means of rotary converters, which comprise two machines on the one shaft, or it may be one machine with two windings. The one machine has slip rings and runs as a motor driven by the alternating current, while the other machine on the shaft is fitted with a commutator and generator continuous current at the designed voltage, say, for traction work, about 500 volts. Polyphase motors have, in common with continuous-current motors, the features of supplying power in a convenient form, while the motors are small and light, easily started, and not noisy, and they do not require constant attention.

Single or monophase motors have the disadvantage, compared with polyphase motors, that some supplementary starting device is required, either some separate machine or some such artifice as phase splitting.

Comparing **polyphase asynchronous motors** with single-phase synchronous motors the practical advantages are largely in favour of the former.

1. The single-phase motor requires only two wires as against three required for three-phase motors, but the weight of copper required for the transmission of a definite quantity of power is less in the polyphase system than in the single-phase.
2. Polyphase motors are self-starting; single-phase motors require some separate starting device.
3. The speed may be regulated, when rotating magnetic fields are employed, by means of variable resistances in the rotor circuit.

4. Polyphase motors have a superior efficiency.
5. It is possible to overload a polyphase motor without any ill effects. This is not so with the single-phase motor, in which the sudden application of even the normal load may put the motor out of step with the current phase and cause it to stop.

Comparing polyphase with continuous-current systems the advantages are still more marked.

1. The polyphase motor involves only a static transformer, which gives increased economy.
2. The economy of copper is greater than in either a continuous-current or a single-phase installation.
3. The cost of upkeep is much less. In the continuous-current motor renewals of the brushes and repair of the commutator involve considerable expenditure, especially when the motor is subjected to sudden variations of the load. Cost of supervision is also less, especially in view of the absence of any brushes or commutator.
4. For motors up to 20 h.p. a starting switch is not necessary. Such switches are indispensable for any continuous-current motor.
5. Although the voltages used are generally higher, a polyphase motor may be subjected to sudden reversals. This is not possible with the continuous motor.
6. The efficiency is about two or three per cent higher.

There is one limitation to the use of alternating currents, namely, that they cannot be used for the chemical transformation of energy, as, for example, the storage of electrical energy by means of accumulators. They are also not available for such processes as electroplating, the reason being that any chemical action produced while the current is in one direction is reversed when the current flows in the opposite direction. The chemical action during one phase is neutralized during the next.

THREE-PHASE SQUIRREL-CAGE INDUCTION MOTOR

Index to the Principal Parts

1. Cast-iron Shell.
2. Cast-iron End Covers.
3. Bearing Shields.
4. Foot Lugs.
5. End-cover Studs.
6. Stator Laminated Body.
7. Stator Winding.
8. Punched Slots.
9. Cast-iron Bearings.
10. Bearing Bushes.
11. Oiling Ring.
12. Set Pin.
13. Rotor Spindle.
14. Keys.
15. Spider (rotor frame).
16. Spider End Ring.
17. Spider Arms.
18. Fixed Flange.
19. End-ring Screws.
20. Rotor Stamped Laminations.
21. Copper Rods of Rotor Winding.
22. Rotor-winding Connections.
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36. Pulley.
37. Pulley Boss.
38. Rotor Set Screw.

Section VI

GAS AND OIL ENGINES

GAS AND OIL ENGINES

THE HISTORY OF THE GAS ENGINE

In 1678 the Abbé Hautefeuille, in France, invented an engine in which the gases developed by the explosion of a grain of gunpowder were utilized to drive a piston against a resistance. Essentially the gas engine in its present-day form is an explosion engine, although the forces exerted by the hot gases are not so sudden or violent as those produced in the cylinder by the explosion of gunpowder. Two years after the publication by the Abbé of his memoirs on *The Raising of Water by Means of Gunpowder*, the Dutch scientist Huyghens published the results of his investigations. In these memoirs he described the first engine made by him, which consisted of a cylinder and piston with two pipe connections and leather valves. The explosion of the powder in the cylinder drove the air out through the leather valves, which prevented its return, and the piston was then driven down by the excess of the external atmospheric pressure. No results of any promise were ever obtained from the engine, and the difficulty of dealing with the enormous forces developed by the explosion led Papin to experiment with a view to finding some less violent and more certain working substance, which would at the same time give a more perfect vacuum. Similar experiments made by Blésois and later engineers led to the development of steam as the working substance, and the great practical improvements effected by Watt and his successors established the steam engine in the favour of engineers to the complete exclusion of all other kinds. It was not until 1791 that the atmosphere-gunpowder-engine idea was revived and that certain improvements upon the Hautefeuille and Huyghens engines were proposed by an English engineer, John Barber. In his patent, which is of the briefest description, he claims the use of a mixture of air and gas and its ignition in an explosion chamber. Several years later, in 1794, another British patent was granted to Robert Street, "for the production of force from inflammable vapour by means of liquid and air, fire and flame, for the purpose of setting in motion engines and pumps". Street's improvement consisted in injecting petroleum or other inflammable liquid into the bottom of a cylinder and there vaporizing it, the pressure thus developed being then utilized to drive the working piston of the cylinder.

Philippe Lebon of Brachay (Haute Marne), the creator of the gas-lighting industry, may be said to equally share the honour of having originated the gas engine, because in 1799 a patent was granted to him for the use of gas in the production of power. The value of gas as an illuminant seems to have been, in the case also of this gifted inventor, a question of secondary importance. Two years later an additional patent was granted to him, wherein he very clearly described a method of electrically igniting the vapour by means of current derived from a machine driven by the engine itself, and also the use of a pump for compressing the mixture of gas and air before the explosion. Had the unfortunate inventor not been assassinated in 1804, the practical introduction of the gas engine would most probably have dated from the commencement of the nineteenth century instead of from a period sixty years later.

From the year 1799 to 1860, when the first gas engine of real practical value was introduced, many more or less ingenious arrangements were proposed. Those of Welman, Wright, Johnston, and Barnett may be cited as of the greatest interest.

Wright's engine was particularly well designed and constructed. It was a vertical double acting engine arranged to drive the crank directly, and the gas in the cylinder was ignited by a heated gas tube. Air and gas mixed in the proper proportions for combustion were supplied to the cylinder by a pump controlled by a centrifugal governor driven by the engine, and in this way the gas supply was varied to suit the speed or power required. Considering the rudimentary state of the gas engine in 1833, Wright's conception was of a remarkably ingenious nature, and many engines of the present day are not in all respects so well designed. It is surprising, therefore, that the introduction of the engine was not successful, but doubtless the indifference of engineers to the system was due to the high favour in which the steam engine was held.

Johnston's engine was also double-acting, but the energy was derived from the combination of two volumes of pure hydrogen with one of oxygen. When ignited, these two gases combine to form a small volume of water, and in consequence of the great reduction in volume a vacuum was formed under the piston. At the same time the upper side of the piston was exposed to the pressure of an expanding gas, which drove the piston into the cylinder. Although the idea was of a most ingenious kind, its practical application was, and is still, impossible, owing to the cost of producing the two gases oxygen and hydrogen.

William Barnett, who was granted a patent in 1838, revived the idea of Philippe Lebon. His engine comprised two pumps, one for the explosive gas and the other for the air, and a working cylinder into which the mixture was forced by the pumps. For the ignition of the mixture a gas jet enclosed within a continuously rotating shield was placed at the end of the cylinder. When the aperture in the shield was directed outwards a small external pilot flame ignited the gas jet, which in turn exploded the cylinder charge as soon as communication with the cylinder was again opened by the further rotation of the aperture. The use of a pilot flame was found to be necessary, as the force of each explosion extinguished the gas jet. This was the first instance of the use of a carrying flame under pressure, the principle of which has since been employed by many designers under improved conditions.

In the succeeding years a number of patents were granted for important improvements of the gas engine. In 1844 John Reynold made use of a platinum wire, brought to incandescence when required by means of an electric battery, and placed in the course of the gaseous mixture for the purpose of automatically controlling the time of ignition. Stephard, in 1850, substituted for the electric battery an electromagnetic machine driven by the engine itself, and in 1857 Barsanti and Matteucci described an atmospheric engine which at a later date was revived by Otto and Langen. The mixture was exploded by electric sparks formed between two platinum points surrounded by the gas, and for the production of the sparks a Bunsen battery and induction coil were used. Two patents were granted to Degrand, in 1858 and 1859, for an engine in which the charge was compressed in the cylinder itself, but the mechanical arrangements proposed were of an impracticable nature. Until the appearance of the Lenoir engine, in 1860, there was no engine of the kind capable of working continuously under actual industrial conditions.

The Lenoir gas engine, built by Marinoni, resembled in outward appearance a horizontal double-acting steam engine. Explosion of the mixture was effected by electric sparks produced between platinum points by the high-pressure discharge of a Ruhmkorff induction coil and battery. At first it was thought that the Lenoir gas engine would entirely supersede Watt's steam engine. Its working was continuous and regular, the cost was moderate, no boiler or skilled attendance was required, and the cost of installing the plant was considerably less; but after the first enthusiasm the inherent difficulties of the system were to some extent realized, and for some time, as a result of the reaction of public opinion, the value of the idea was unjustly depreciated. Compared with a steam engine of equal power, the upkeep of the gas engine was found to be considerably greater, and the consumption was as great as 100 cu. ft. per horse power-hour. Four times as much water was used in the cylinder jackets of the gas engine as in the condenser of the steam engine; and, lastly, a continuous and abundant supply of oil was essential to ensure continuous running. The defects were considered insurmountable, and, after the first favourable reception, it was abandoned by all the users by whom it had been installed. Encouraged by the first success of the Lenoir engine, considerable attention was given to the subject by other investigators. One of the first of these, M. Hugon, introduced in 1862 an engine built according to his patent of 1860. After the explosion the cylinder was cooled by the injection of a fine spray of cooling water. From experiments made with the engine by M. Tresca the consumption of gas appears to have been 86 cu. ft. per horse-power-hour. As a result of the injection of cooling water the temperature of the exhaust gases was 186° C., as compared with 280° in the Lenoir engine, and the upkeep of the engine was thereby very considerably improved.

Several arrangements of British origin were patented in 1861, but none involved principles that were new. The engine by Kinder and Kinsey may be mentioned as of this period, and also that of Millon, who revived the original idea of Lebon by compressing the charge in the cylinder before exploding it.

On the 7th January, 1862, M. Beau de Rochas obtained a patent which marks an important epoch in the history of the gas engine, because in it are described the

conditions that must be satisfied to obtain truly economical results. It was M. Beau de Rochas who invented the four-period cycle, upon which the majority of modern systems are based. During the first outward stroke of the piston the explosive mixture is drawn into the cylinder, and compressed on the return stroke. Ignition then takes place at the dead point or thereby, and the exploded gases expand and drive the piston during the third stroke of the cycle. On the fourth stroke, now called the scavenging stroke, the return of the piston expels the burnt gases from the cylinder, which is then ready to receive a new charge and to repeat the cycle.

While rendering to this highly-scientific engineer all the honour that is his due as the expounder of the fundamental principles underlying the design of the truly economical gas engine, it must be remembered that his role was more that of the mathematician than the practical engineer. He demonstrated the scientific principles without indicating any mechanical means of realizing the results of his theories. No explanatory designs are included in his patent, and the questions of the distribution and ignition of the mixture and the exhaust of the products of combustion are left unconsidered.

M. de Rochas never built his engine, and by his failure to pay the second annuity the patent lapsed and thus became public property. With the lapse of the patent the very valuable contents were forgotten, until several years later they were revived by Otto, who, for the first time, realized the theories of Rochas in a practical form. At the International Exhibition at Paris in 1867 there was installed a vertical atmospheric gas engine based on the primitive principle of the original Hautefeuille powder engine. This engine, which was built by two German engineers, Otto and Langen, was essentially an improvement upon the Barsanti and Mateucci system introduced about ten years earlier. The explosion of the gaseous mixture served the purpose of merely creating a vacuum under the piston, the moving agent being the pressure of the atmosphere. This engine, which greatly excelled the earlier attempts of Lenoir and Hugon, consumed only 47 cu. ft. of gas per horse-power-hour, as compared with the 85 to 100 cu. ft. gas consumption of the other machines. Financially the engine was a great success, the inventors having sold over 5000 in a few years; but the defects of the system were very apparent. The shocks were severe, and the rattle of the driving chain and the explosions of the charges made a continual noise, resembling the discharge of small arms. On the other hand, the lowness of the consumption, which had been reduced by 1872 to 28 cu. ft., more than counterbalanced the defects in the opinion of users, as the steam engines of those days could not be made to give the same economical results. A second horizontal type of engine was introduced by Dr. Otto in 1878. It was based upon the four-period cycle described in the patent of Rochas; but as Dr. Otto was most probably unaware of that previous work, the system is generally known at the present day as the Otto cycle. The superiority of the new engine over all others was at once recognized, and over 35,000 were installed by engineers in all parts of the world. Many imitations were soon placed upon the market, and for some time Otto was engaged defending his patent rights. In England the patents were upheld, but in France they were declared to be anticipated by the patent of Beau de Rochas, and accordingly, in 1892, Otto's French patents of 1876 and 1877 became public property. With Otto, however, remains the credit of having introduced the four-stroke cycle, although, as the French court

declared, he may not have been its originator. At the same exhibition of 1878 at which the Otto engine first appeared other gas engines were also exhibited. One was built by Mignon and Rouart to the instructions of the inventor Bisschop; another was the Simon engine; and a third the Ravel gas engine, which will be described later. Although the Simon engine is no longer built, it gave most promising results, and the economy was considerable. Combustion of the mixture took place gradually and slowly, and the heat of the waste gases was utilized to produce the steam which was made to assist the gas at the moment of explosion, as in the Hugon system. This additional action was so considerable that the engine could be run for several revolutions under the action of the steam alone, after the gas supply had been cut off. One h.p. hour could be obtained with a consumption of 28 cu. ft. of gas and 1 gal. of water. With the Ravel engine a still better economy was obtained, the consumption being about 20 cu. ft., but the working of the engine was less satisfactory, owing to the bad design of certain of the mechanical parts.

Such was the state of the gas-engine industry in 1878. The machines in general worked admirably, and all that was required was the perfection of details to permit of the gas engine successfully competing with the steam engine.

During the period that followed 1878 many systems were proposed, the most remarkable of which were: the two-cycle engine of Dugald Clerk in 1879; the single-acting engine of Lenoir (1883), in which the charge was compressed before explosion and the cylinder was cooled by a scavenging current of cold air; and in the same year the six-cycle engine of Griffin. At the Antwerp exhibition of 1884 several engines of more recent construction were exhibited by Andrews (Stockport), Bénier, Koerting, and Benz. There appeared at the same time a very remarkable engine called the Simplex, which was built at the works of Messrs. Powell, of Rouen (now Matter & Co.), to the instructions of the designers, Messrs. Ed. Delamare-Deboutteville and L. Malandin. In an action instituted against them for infringement of the Otto patent, the inventors of the Simplex engine had very little difficulty in proving the novelty and the many improvements embodied in their arrangement.

From 1855, and following the appearance of the new Lenoir and the Simplex engines, the majority of engineers adopted the Beau de Rochas or Otto four-period cycle, and at the end of this epoch the first carburetted-air engine, driven by the combustion of light petroleum oil, made its appearance. Among the later examples of the time may be mentioned those of Durand, Daimler, Tenting, Koerting-Boulet, Diederichs, Gotendorf, Noël, Forest, and Ragot, and the six-cycle engine of Rollason and Atkinson. At the International Exhibition of 1889 fifty-three machines, representing a total of about 1000 h.p., were exhibited by thirty-one different makers. Of these engines all excepting four worked on the Otto system. For the first time there was exhibited an engine which, instead of using ordinary rich and costly lighting gas, was driven with a cheap gas of lower calorific value generated in a special producer. This 100-h.p. Simplex engine opened a new field for research, and at the same time demonstrated the future possibilities of large unit engines driven by cheap producer gases.

Large gas engines driven by waste furnace gases are extensively used on the

Continent with considerable success, but the same good report cannot be given of similar British installations, which have proved so far to be both irregular in their action and unreliable. With further experience there is no doubt that these difficulties will be entirely overcome, and that it will be possible to utilize with great economy the enormous quantities of heat energy in the waste gases from blast furnaces.

The history of the gas engine may be divided into three distinct periods. During the first period, the period of invention, extending to the year 1860, the principles were formulated and the requirements considered from many points of view, but the ideas were not practically realized. M. Lenoir, in the second period, brought the original vague and abstract theories of his predecessors into more definite order, and by the construction of an actual machine based on the principles indicated by Lebon he directed the course of future developments. From 1889 onwards may be considered as the third period, in which details were gradually improved and the powers of the engines increased up to 200 to 400 h.p. With the introduction also of producers generating "poor" gases, the gas engine was enabled to compete with the steam-engine plant, which may be very largely superseded in the near future.

THE ACTION OF THE GAS ENGINE

All prime movers derive their power either directly or indirectly from heat, and between the power developed and the heat expended there is a definite relationship which has been expressed by Mayer as follows:—Whenever work is expended upon or done by a substance, a definite quantity of heat appears or disappears. The quantities of the work and the heat are interdependent, and bear to one another a definite and constant relationship. By experiment the value of the relation has been determined, and names have been given to the units of heat and of work. In France the unit of heat is the *caloric*, and this term is being more generally adopted in other countries. The French unit of work is called a *kilogram-metre*. In Britain the unit of heat is called a *thermal unit*, and the unit of work a *foot-pound*. The ratio of the French units has been experimentally determined as 427, that is to say, the heat (1 calorie) required to raise by 1° C. the temperature of 1 kilogramme of water at the point of maximum density is equivalent to the work done by or developed in the movement of 427 kilogrammes through a vertical distance of 1 metre. A British thermal unit is the heat required to raise 1 lb. of water at the point of maximum density through 1° F., and is equivalent to 778 ft.-lb.

In all the thermal engines at present known, the heat energy is converted into mechanical work through the intermediary of some working substance such as steam, air, or gas, and not directly. Direct transformation of heat into electrical energy is possible, with, however, a considerable loss in the process; and under any circumstances at the present time only a small proportion of the available energy can be usefully transformed. For example, the calorific value of 1 lb. of good coal may be taken as 15,000 British thermal units, equal to about 12,000,000 ft.-lb., but a good boiler and

steam engine together would not give more than one-twelfth part of the total amount as useful work at the engine shaft. This enormous waste, to the reduction of which every effort has been made, shows how very defective are the principles of the present heat engines. The future may have in reserve some more economical system, which will revolutionize the industry of the world, but as yet, apart from the more efficient gas-engine system, there are few indications as to how these desirable results are to be attained.

Theoretically, the work that may be derived from a given quantity of heat depends upon the temperatures at which the heat is taken in and finally rejected. Carnot's "Second Law of Thermo-dynamics" asserts that "it is impossible by the unaided action of natural processes to transform any part of the heat of a body into mechanical work, except by allowing heat to pass from that body into another at a lower temperature". The ratio between the work developed and the quantity of heat expended is a measure of the perfection of the engine, and determines the value of its thermal efficiency. Compared with steam the combustion of gas in the engine cylinder admits of a much greater range of temperature between the reception and rejection of the exploded mixture, and therefore of a greater efficiency. An initial temperature of 1600° C. is obtainable in the cylinder at the moment of explosion; but practical considerations and the nature of the materials of construction limit the initial temperature. At 400° C. iron becomes dull red hot, and at this temperature the lubricating oils in contact with it become vaporized and lose their properties. In air at a temperature of 300° C. oil oxidizes, forming solid carbonaceous deposits of soot, which in an engine seriously affect the working. The difficulty of lubricating the cylinder at high temperatures limits the efficiency of the gas engine, and real improvement will only be effected when some lubricant is found capable of resisting the highest temperatures. Under present conditions, in order to ensure efficient lubrication it is necessary to cool the cylinder walls to a very considerable degree, although by doing so the economical condition of a high initial temperature is seriously departed from. Hot air and gas are theoretically more efficient as working substances than steam, because with them it is possible to obtain a greater range of temperature, and from practical considerations gas is preferable to hot air, because when using gas the weight of the engine may be reduced very considerably, as the pressures are higher and the volumes smaller. It is not the intention here to study the theory of the hot-air engine, which has been entirely superseded by the gas engine. From what has been said above, it will be evident that the thermal conditions are greatly in favour of the latter.

It seems difficult at the present day to devise a gas-engine cycle or combination that has not already been repeatedly experimented upon. The number of different arrangements is endless, and many that are brought forward as entirely novel are merely adaptations or revivals of one or other of the early schemes proposed by Lebon, Barnett, Beau de Rochas, and particularly by Otto.

Apart from the design of details there is a great general resemblance between the gas engines of different makers, and in many cases the same engine is arranged to consume either illuminating gas or producer gas.

To distinguish the different types according to their systems of working, M. Witz has proposed the following four groups:—

I. Explosion without compression.
II. Explosion with compression.
III. Combustion with compression.
IV. Atmospheric and mixed.

TYPE I. Explosion without Compression.	TYPE II. Explosion with Compression.	TYPE III. Combustion with Compression.	TYPE IV. Atmospheric.
(1) Suction of the mixture under atmospheric pressure.	(1) Suction of the mixture under atmospheric pressure.	(1) Suction of the mixture under atmospheric pressure.	(1) Suction of the mixture under atmospheric pressure.
	(2) Compression of the gas and air mixture.	(2) Compression of the mixture.	
(2) Explosion at constant volume. Driving stroke.	(3) Explosion at constant volume. Driving stroke.	(3) Combustion at constant pressure. Driving stroke.	(2) Explosion at constant volume. Stroke unresisted.
(3) Expansion	(4) Expansion.	(4) Expansion.	(3) Expansion.
			(4) Return of piston under the pressure of the atmosphere. Driving stroke.
(4) Return stroke and exhaust of burnt gases.	(5) Return stroke and exhaust of burnt gases.	(5) Return stroke and exhaust of burnt gases.	(5) Return stroke driving out the burnt gases.

To the first group belongs the engine devised by Lenoir in 1860. During the first half of the stroke the piston draws in the mixture of air and gas. Communication with the atmosphere is then closed, and on the explosion of the charge the piston is driven to the end of its stroke. On the return stroke the exhaust is opened, and the piston sweeps out the residual burnt gases. Before ignition takes place the mixture may first be compressed either in a special reservoir or in a prolongation of the cylinder called the compression chamber. This is the arrangement mentioned above under group II. In engines of the third group the gas mixture is burned gradually under a steady pressure, instead of being exploded suddenly, the charge being in some cases initially compressed, and in others not. Typical engines of the third group, in which initial compression is adopted, are those of Simon and Brayton. Explosion of the gases in engines of the fourth group does not directly supply the driving force, but merely serves to produce a vacuum under the piston, which is then driven by the external pressure of the atmosphere or of steam. This arrangement was at an early date completely abandoned in favour of a "mixed" system, in which the upward movement of the piston, under the force of

the explosion, was employed in doing useful work. The Bisschop engine is a representative of this double-acting type.

The cycles of these four groups have been so arranged in tabular form that the sequence of the changes occurring under the piston may be compared at corresponding periods before and after combustion, but the number of the strokes is often varied by the addition of a supplementary compressor, as in the two-cycle engines devised by Dugald Clerk. The table has been taken from the very comprehensive work by Aimé Witz, entitled a *Traité théorique et pratique des moteurs à gaz*. As it is intended to devote the present chapter to the consideration of such gas engines as have satisfied the practical requirements of users, engines of the hot-air type will not be considered here.

TYPICAL GAS ENGINES

The First Lenoir Engine.—In external appearance this engine, illustrated in fig. 320, bore a marked resemblance to the ordinary type of double-acting horizontal steam engine with flywheel and connecting rod, with which designers were already very familiar. Gas was merely substituted for steam, with very few alterations of the parts, and the distribution was effected by ordinary slide valves operated by two eccentrics. For the ignition of the mixture an electric spark was passed between two points inside the cylinder when the piston reached its mid-stroke position, and for the production of the high-tension spark a Ruhmkorff coil and batteries were supplied. During the latter portion of the forward stroke the drive took place, and on the return stroke the exhaust gases were driven out, while the other face of the piston was acted upon by the driving force. Around the cylinder walls cold water was circulated to prevent the temperature from becoming abnormal. This double-acting arrangement, which does not permit of initial compression of the mixture, has been abandoned by all designers, because the regularity of the action is obtained at the expense of the economy, and owing to the successive actions on the two sides of the piston, the quantity of gas burned is out of all proportion to the power developed.

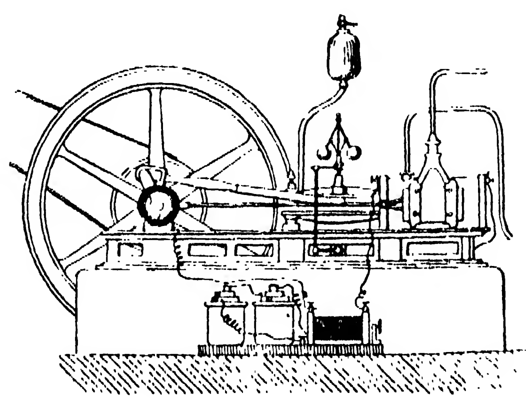


Fig. 320.—The First Lenoir Gas Engine, 1860.

Bisschop Engine.—Fig. 321 illustrates this engine, which works on the mixed principle of the Otto and Langen atmospheric engine. Expansion of the exploded gases raises the piston, which is then driven, during the working stroke, by the pressure of the atmosphere. Very successful results were obtained from the first engines, which were well designed and constructed, but very few examples now exist. As will be seen from the illustration, the engine, which was of small power, was of a vertical type, with the piston crosshead guide surmounting the cylinder. On the outside of the

cylinder were cast numerous ribs of metal, which, by providing a large air-cooling surface, served the same purpose as a water jacket.

In 1880 the inventor was awarded a prize of 1000 francs for his engine, which was considered the best low-power engine suited to the requirements of small users.

François Engine.—This engine was a complicated development of the Bisschop engine, but it never succeeded in displacing the latter from public favour, as the complication of the arrangement was out of all proportion to the very moderate results obtained. Two shafts, placed symmetrically above the cylinder end, were directly driven by two connecting rods from the piston, the shafts being geared together by means of toothed wheels. After a short existence the system was completely abandoned.

Laviornery Engine.—Use was made in this engine of the vertical arrangement commonly adopted in the steam hammer, that is, with the inverted cylinder above the shaft, which was driven in the usual direct way through a piston and a connecting rod. Regulation of the speed was effected by a governor which controlled a throttle on the gas admission pipe, an arrangement commonly adopted in the early engines of smaller powers. At a later date Mr. Laviornery introduced a horizontal two-cycle type, which gave a considerably improved economy.

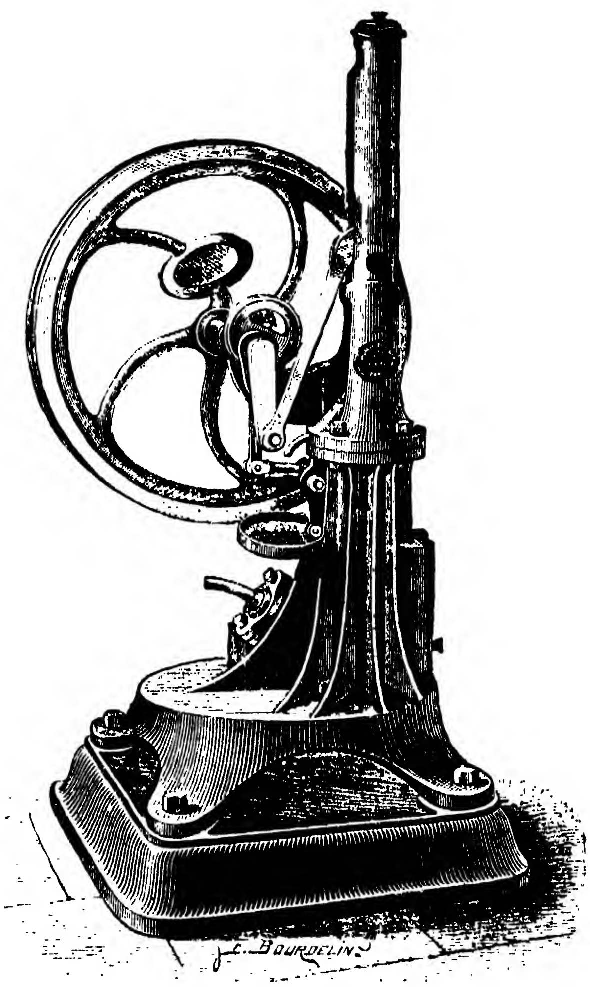


Fig. 321.—Early Bisschop Gas Engine

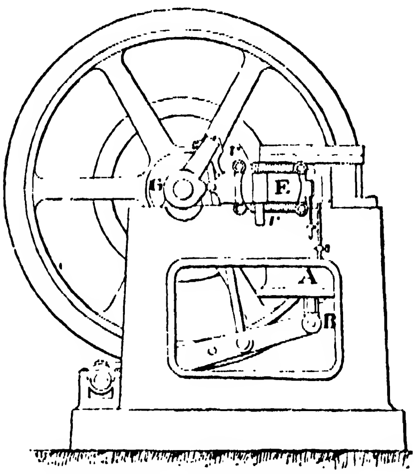


Fig. 322. Early Bénier Gas Engine

Bénier Engine.—This simple engine was the first one made by the designers of the Bénier producer engine. As will be seen from the illustration (fig. 322), the cylinder A was inverted, and the crank was driven through a connecting rod coupled to a side lever, the end B of which received its motion from the piston rod. A cam G on the shaft operated a single slide valve E, controlling admission

and ignition, and side springs *r, r* were provided to keep the cam and slide always in contact. Air and gas in the proper proportions were drawn in by the piston until the middle of the stroke, when the mixture was ignited by the exposure of a flame at the admission port, and the explosion took place. A pilot flame was provided for the relighting of the ignition jet after each explosion. A second cam on the shaft opened a separate exhaust valve at the proper moment. Water-cooling jackets kept the heat of the cylinder within reasonable limits, and the economy obtained in actual practice was quite satisfactory, the consumption being about 50 cu. ft. per horse-power hour. Towards the year 1880 the system received a certain amount of attention, owing to the simplicity of the design and the relatively small cost.

The **Economic motor,** which was first constructed in New York about the year 1883, was a small type of engine rarely exceeding $\frac{1}{2}$ h.p., and working on the non-compression system. Its arrangement was ingenious but somewhat complicated, as will be seen from the illustration, fig. 323. A is the cylinder, provided with external air-cooling ribs, and G E is the rocking lever from which the crank O C received its motion through the connecting rod B. Regulation of the speed was effected by means of a centrifugal governor throttling the gas admission, as in the other engines of the same class. It is understood that the results obtained in practice were satisfactory.

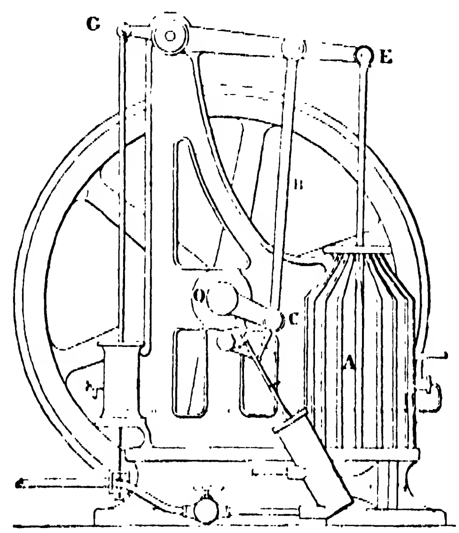


Fig. 323. The Economic Gas Motor

Lenz Engine.—It would be difficult to devise a simpler engine than the Lenz one, which has the minimum number of working parts. The mixture is drawn automatically through a spring-loaded valve, and the ignition takes place in the admission passage itself, on the application of a flame. The force of the explosion is made use of for closing the valves, but on the return of the piston the exhaust valve placed at the lower end of the cylinder is opened by a special cam on the engine shaft. Instead of the usual water jackets the cylinder was built in two parts, separated at the joining by a layer of non-conducting material. To reduce the shock on the crank at each explosion, the head of the connecting rod was forked to engage the crank pin, and the actual drive took place through a compressed spring between the head and the pin. By these means the smoothness of running was greatly improved.

Dugald Clerk Engine.—In the design of a gas engine the ideal arrangement is to have an explosion, that is, an impulse, every stroke, and for many purposes the very usual Otto cycle having one impulse every four strokes is not sufficiently good. Many attempts have been made to devise a satisfactory two-cycle engine, but the experimenters have, in general, found that the problem is more difficult in practice than in theory. Dugald Clerk's engine, which first appeared in 1881, was the earliest of the two-cycle types, and his name is generally associated with such engines. It was of the simplest

possible design, the use of gear wheels being avoided, and in actual use the working was very regular and noiseless (see fig. 324). Two cylinders were arranged side by side on the overhanging end of the bed plate; the one serving as a single-acting engine, and the other as a compressor for the explosive mixture; that is, the mixture was compressed in a separate cylinder instead of in the working cylinder, as in engines of the four cycle type. After the transfer of the compressed charge into the working cylinder, the compressor was arranged to entrap and compress a quantity of air, which was later used for sweeping out of the cylinder the exhaust gases resulting from the previous explosion. By the use of the second cylinder it is possible to dispense with half the strokes of the Beau de Rochas cycle, and to have one impulse for each

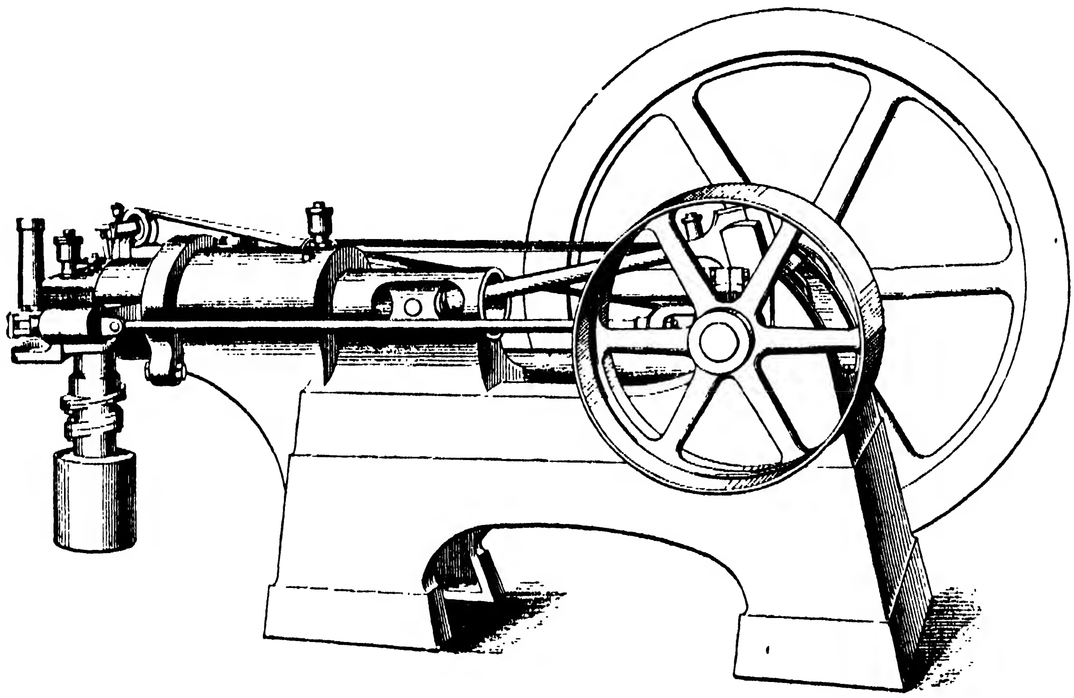


Fig. 324. Dugald Clerk Gas Engine

revolution of the crank. Combustion which takes place at constant volume is more complete and instantaneous, but the expansion is greater, notwithstanding that the output is increased. It should be mentioned that the ignition is effected by the carriage of a flame from the ignition jet to the combustion chamber by means of a slide valve provided with suitable passages. A water jacket round the cylinder keeps the temperature from becoming excessive, and by a special arrangement the two cylinders could be made to work on the compound principle by allowing the gases, after their expansion in the working cylinder, to act on the forward face of the second (compressor) piston. Exhaust then took place in the ordinary way, but from the compressor instead of from the working cylinder. In spite of its many excellent features the engine never competed successfully with the somewhat more economical engines of the Otto type, and at the present time the system has been almost wholly abandoned.

Benz Engine. Special means are adopted in this engine for the more complete exhaust of the burnt gases, by the injection into the cylinder during the latter half of the

scavenging stroke of a certain volume of compressed air, which effectually sweeps out the waste products and also fills the clearance spaces. A small auxiliary pump introduces the charge before the commencement of the compression, which thus takes place in the working cylinder itself. A small magneto, driven by the engine, produces electric sparks between the points of the ignition plug shown in fig. 326 whenever the explosion of the charge is required. From the sectional elevation of the cylinder, fig. 325, and the sectional plan, fig. 326, it will be seen that the cylinder is closed at both ends, thus enabling the front face of the piston to be utilized as an air compressor, which maintains in an auxiliary reservoir a constant pressure of air. The presence of the cold air at the front side of the piston has a very considerable cooling effect upon the hot cylinder walls, and efficient lubrication of the internal working surfaces is accordingly less difficult. Additional cooling is obtained in the usual way by means of water circulation around the cylinder exterior, about $1\frac{1}{2}$ cu. ft. of cooling water being required per horse-power hour to keep the temperature at 75° C. The Benz engine, which is manufactured in France, has been very successfully applied to work of all descriptions—the driving of pumps, dynamos, launches, and latterly of motor cars, and its use in other countries is becoming very general.

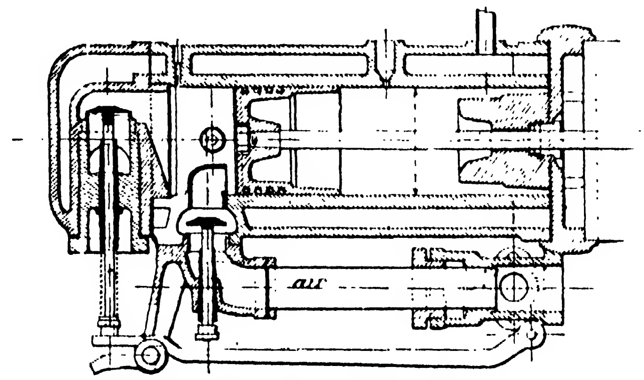


Fig. 325.—Sectional Elevation of Benz Engine Cylinder

Ravel Engines.—Mr. Ravel's engine, which was first exhibited in Paris in 1878, worked on what was called the "variable centre of gravity" principle. It consisted of an oscillating cylinder carried on trunnions, and of a very heavy piston, which served the sole purpose of an overbalancing driving weight. On the explosion of the charge the heavy mass was driven to the upper end of the cylinder, where it overbalanced and caused the whole cylinder to turn about its trunnions, which were extended to form the driving shaft. The periodic effort of the explosions kept the cylinder and shaft in continuous rotary motion. From 18 to 20 cu. ft. of gas were consumed per horse-power hour, but the mechanical details of design were not sufficiently well thought out, and the engine frequently stopped. Mr. Ravel abandoned this early idea, and in 1885 introduced a second arrangement based on Clerk's two-cycle system. One cylinder,

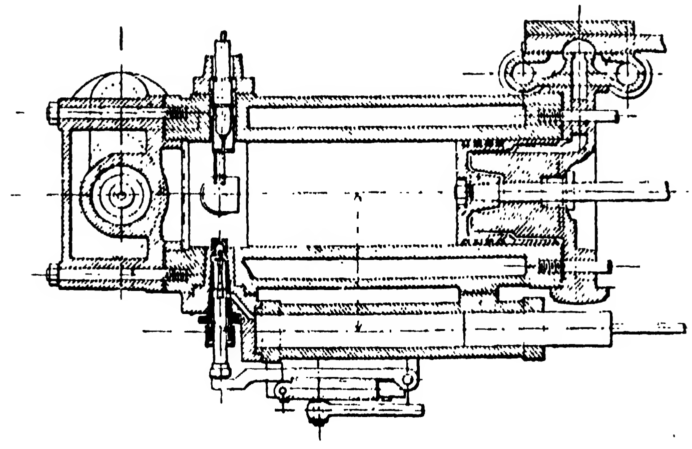


Fig. 326.—Sectional Plan through Benz Engine Cylinder

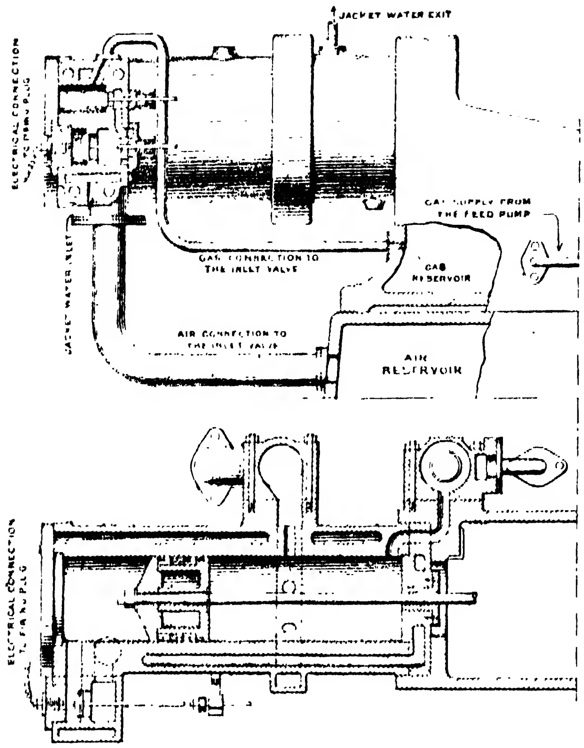


Fig. 327.—Cylinder of Ravel Engine

fig. 327, closed at both ends, was used, the front chamber of which served as an air compressor during the forward stroke of the piston, and the back portion as the working cylinder. Although the consumption only slightly exceeded that of the Otto engine, and the regularity of the working was superior, the Ravel engine never competed successfully with the Otto engine.

The Midland Engine.—As will be seen from fig. 328, this double-acting engine comprised two equal cylinders arranged side by side, with a pair of connecting rods driving two cranks set at an angle of 65 degrees to one another. One of the cylinders acted solely as a compressor for the explosive mixture, which was transferred at the proper moment to the other cylinder, in which the exploded mixture exerted its driving force.

There are many other types of two-cycle engines, but space forbids further reference

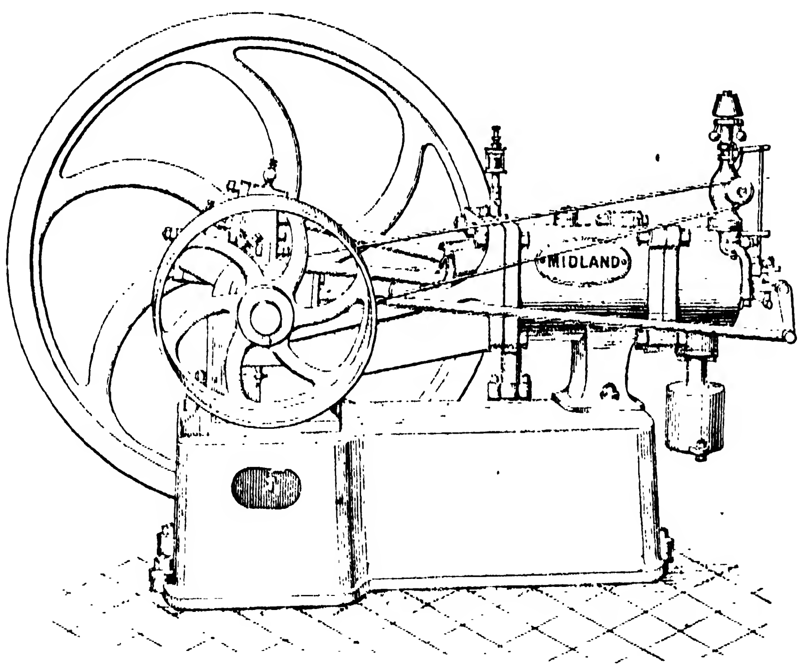


Fig. 328.—Midland Gas Engine

to them here. Descriptions of these engines are given in considerable detail in the treatise by M. Witz on *The Theory and Practice of Gas and Oil Engines*, already referred to. The Bénier two-cycle producer-gas engine will, however, be dealt with

later, when treating of engines driven with poor gases, as certain novel and interesting features are involved in it. The following section deals with four-cycle engines introduced by Beau de Rochas, but first practically realized by Dr. Otto in 1887.

The Otto Engine.—A general description now of the principles upon which the Otto engine is based will save further repetition when dealing with the engines built by other makers, which work on the Otto cycle, or on some very analogous system. From the first introduction of the Otto engine the successful results obtained ensured

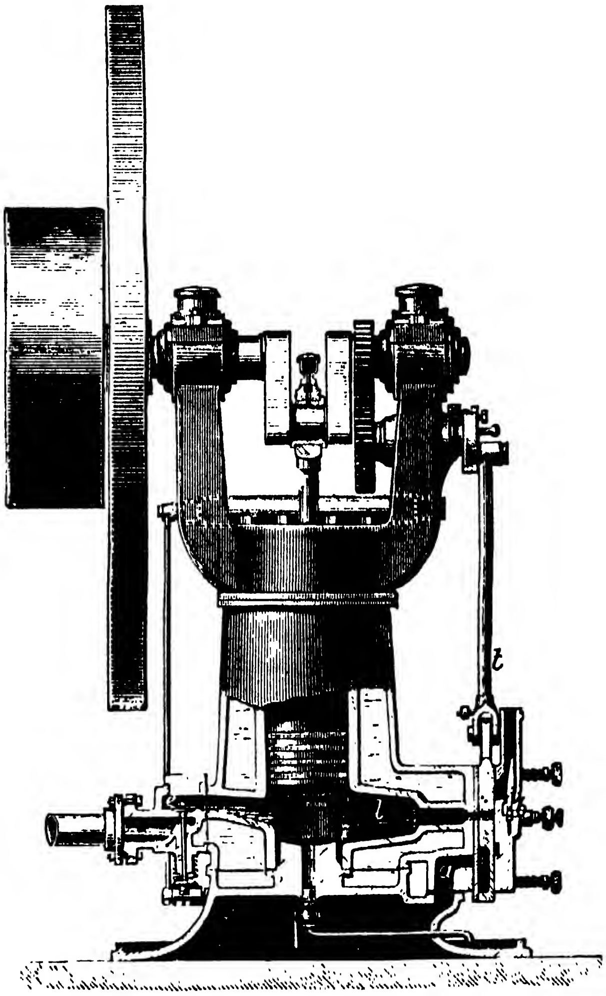


Fig. 329.—Early Otto Vertical Gas Engine

its very general adoption, and on the expiry of the patents many imitations and improvements of more or less value were introduced by other manufacturers.

A partial section through the cylinder, compression chamber, and slide valve of a vertical engine of the Otto type is given in fig. 329. An enlargement *l* of the cylinder bottom serves as a chamber for the compression of the explosive mixture of gas and air, which is sucked in during the upward stroke of the piston and compressed on the return to a pressure of from three to four atmospheres. At this pressure, when the piston has reached the end of its stroke, the gas jet *b* is exposed to the explosive charge in the cylinder by the movement of the slide valve operated by the connecting rod *t*. Explosion then takes place, and the temperature rises to about 1500° C., the

driving pressure being about 185 lb. per square inch of the piston area. On the return of the piston to the bottom of the cylinder, that is, during the fourth stroke corresponding to the final half of the second revolution of the crank, the burnt gases are expelled to the atmosphere under a pressure of from 2 lb. to 4 lb. Water jackets are fitted around all the portions of the engine that are subjected to the high temperature of the exploded gases. Attention was particularly directed by the designer to the question of the reduction of the gas consumption, and good results were obtained by diluting the mixture with a proportion of the waste gases resulting from the previous explosion. By diluting the mixture in this way the charge was consumed more gradually instead of explosively. It was found that the low consumption was not wholly due, as claimed,

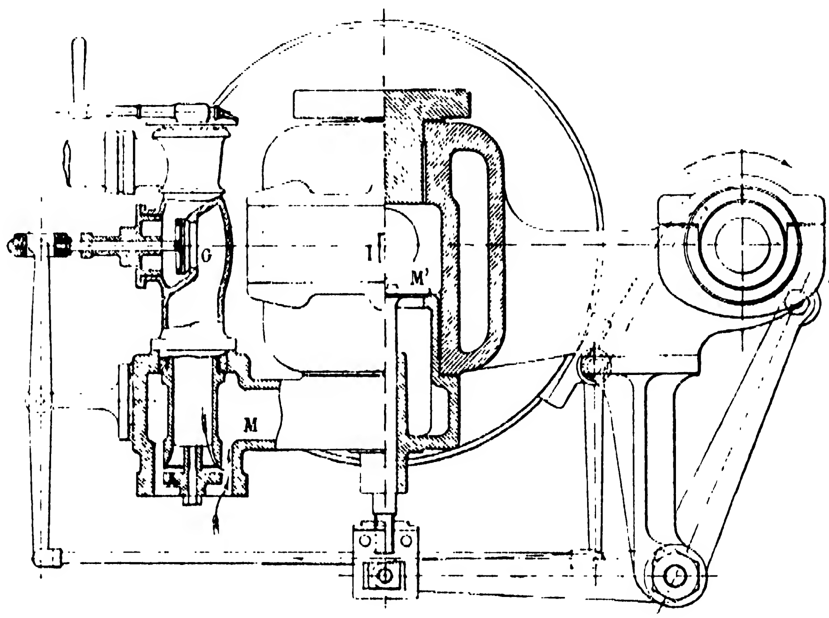


Fig. 330. End View of Otto Valve Arrangement.

to the superposed arrangement of layers of gas and air in the cylinder, but to a certain action of the walls.

Mechanically, the Otto engine was an excellent example of good design and simplicity of arrangement. Admission and exhaust were controlled by means of cams, and ignition of the charge was effected by the transport of a flame under pressure. When the speed exceeded a certain fixed limit, a governor acting on the "hit and miss", or, as it is called by French engineers, "the all or nothing", system, suppressed the admission until the speed again became normal. Motion was transmitted to the crank in the usual way by means of a connecting rod, and a specially heavy flywheel was employed for the storage of sufficient energy during the working stroke to ensure some regularity of running during the three remaining idle strokes of the cycle. The consumption was about 28 cu. ft. of gas per horse power hour.

Fig. 330 is an end view in partial section showing the arrangement of the valves adopted by Dr. Otto in his early engines and the arrangement of the levers for operating them. A section through the mixture admission valve M' and the ignition slide and port *I* is also given in fig. 331.

GAS ENGINE

Index to the Principal Parts

1. Cylinder.
2. Water Jacket.
3. Cylinder Head.
4. Engine Frame.
5. Outer Main Bearing of Shaft.
6. Inner Bearing.
7. Engine Base.
8. Fixing Bolts.
9. Piston.
10. Piston Rings.
11. Piston Rod.
12. Cross Head.
13. Cross-head Pin.
14. Connecting Rod.
15. Crank Pin.
16. Crank Webs.
17. Crank Shaft.
18. Flywheel.
19. Driving Pulley.
20. Bevel Gear on Crank Shaft.
21. Bevel-gear Wheel on Valve-cam Shaft.
22. Valve-cam Shaft.
23. Slider Crank.
24. Slider Pin.
25. Slider.
26. Diaphragm Plate in Cylinder Head.
27. Slider-cover Holder.
28. Slider Cover.
29. Adjustable Slider Springs.
30. Adjusting Heads.
31, 32, 33. Bearings of Valve-cam Shaft.
34. Bearing Bracket.
35. Air-admission Pipe.
36. Air Chamber.
37. Gas-admission Pipe.
38. Gas Stop Cock.
39. Gas-regulating Valve.
40. Gas Connection to Slider.
41. Lever operating Regulating Valve.
42. Lever operated by 41.
43. Cam controlled by the Governor.
44. Bell-crank Notched Lever of Governor.
45. Tripper Blade.
46. Governor Bracket.
47. Governor Bevel Wheel on Valve Shaft.
48.* Bevel Pinion on Governor Spindle.
49.* Governor Spindle.
50. Sleeve.
51. Governor Balance Weight.
52. Governor Balls.
53. Governor Casing.
54. Exhaust-valve Cam.
55. Roller on Exhaust-valve Lever.
56. Exhaust-valve Lever.
57. Spindle of 56.
58. Spiral Spring for 56.
59. Exhaust Valve.
60. Exhaust-valve Box.
61. Exhaust Outlet from Cylinder.
62. Exhaust-lever Starting Pin.
63. Spring for 62.
64. Water-circulation Inlet Pipe.
65. Water-outlet Pipe.
66. Lubricator.
67. Oil Pipes.
68. Oil-distributor.
69. Worm Wheel.
70. Worm.
71. Lubricator Pulley.
72. Ignition Chamber.
73. Ignition Gas Pipe.
74. Ignition Tube.
75. Exhaust Outlet.
76. Slider Guide.

* Nos. 48 and 49 are the upward continuation of No. 50, under No. 51

Gas enters through the valve G, which is opened at the correct moment by a system of levers operated from a cam on the half-speed shaft at the right side of the engine, and the mixture of gas and air is sucked as shown by the arrows into the chamber M and thence through the valve M' into the cylinder. An external view of an Otto engine is given in fig. 332.

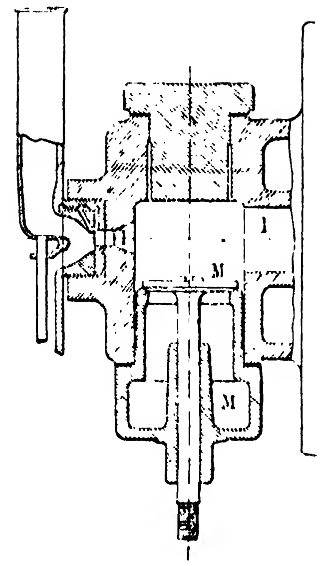


Fig. 331.—Section of Ignition Slide and Admission Valve

To Dr. Otto belongs the credit of having first introduced the gas engine in a really practical form, and of indicating the direction of future developments. Other engineers, following the lead of Otto, have improved the details of construction, and the consumption of gas, to a very considerable extent by reducing heat losses and increasing the expansion until at the present time the gas engine is able to compete with steam under most industrial conditions.

A few of the more remarkable types introduced during the last twenty-five years will be now briefly described, in order to illustrate the development of four cycle engines that has taken place.

Lenoir Engine. In this engine, which first appeared in 1883, the inventor introduced the experience of twenty-five years of continuous experiment and work. The cylinder which overhung the base was provided externally with air-cooling vanes,

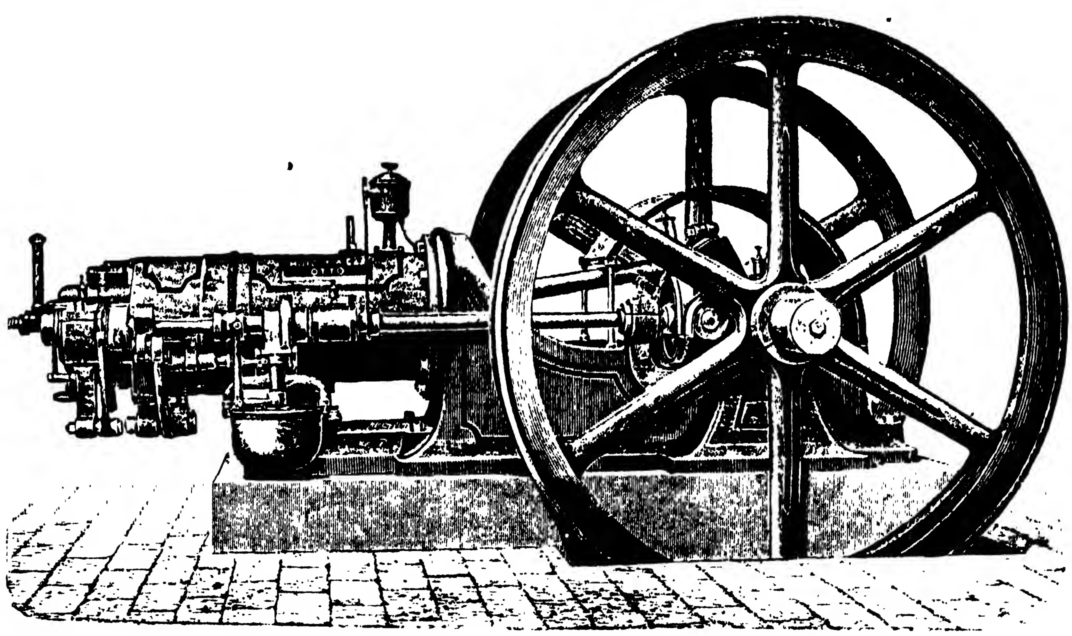


Fig. 332.—Otto Gas Engine with Double Flywheels, designed for extra running

as illustrated in fig. 333, and the crosshead was guided in a bored out trunk in line with the cylinder. Electric ignition was adopted, the spark being produced by a battery in conjunction with a Ruhmkorff coil. About 28 cu. ft. of gas were consumed per horse-power hour. Two other Lenoir engines burning petroleum vapour have been

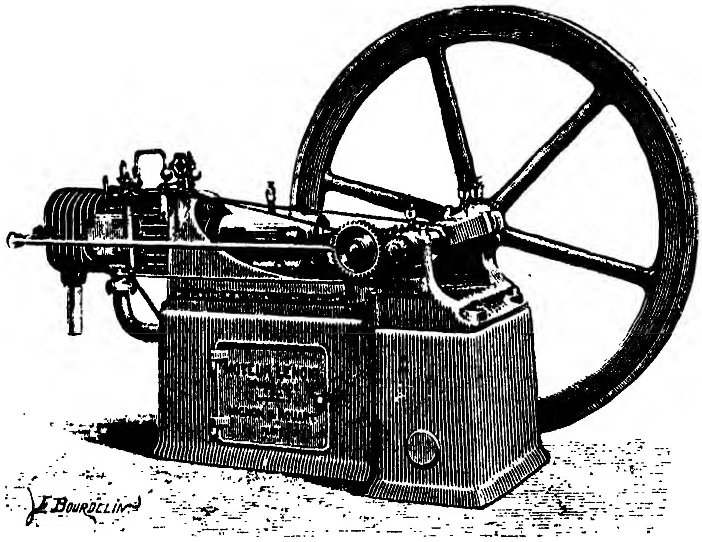


Fig. 333.—Early Lenoir Engine

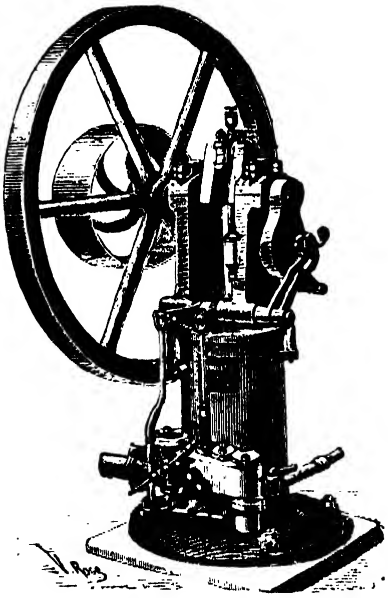


Fig 334.—Early Vertical Koerting-Lieckfeld Engine

introduced, one of them being specially arranged for motor-car work. These will be described later when dealing with oil engines.

Koerting-Lieckfeld Engine.—For the first of these engines, built about the year 1877, the two-stroke cycle of Dugald Clerk was adopted, but the system was abandoned

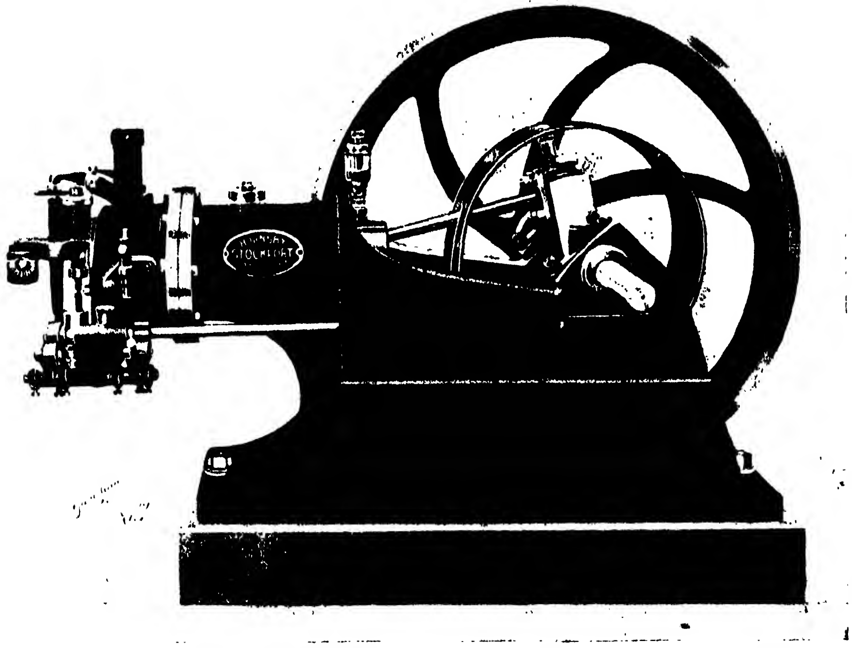


Fig. 335.—Hornsby-Stockport Gas Engine

in favour of the four-stroke cycle of Dr. Otto. An engine working on that system was devised by Messrs. Boulet (Brule et Cie) of Paris, and the actual engine embodied many excellent features. Fig. 334 shows a vertical arrangement of the engine in which

all the parts are carried upon one column, the lower portion of which serves as the cylinder, and the upper as the guides for the crosshead and the bearings of the shaft. A spur wheel on the main shaft engages with a second wheel carrying the cams, which work the valves through a system of levers and a rocking shaft, shown in the illustration, near the top of the cylinder. A centrifugal governor controls the admission, and the flame ignition arrangements are of the simplest description. From actual tests the consumption of gas was about 28 cu. ft. per horse-power hour for an engine of 8 h.p. or

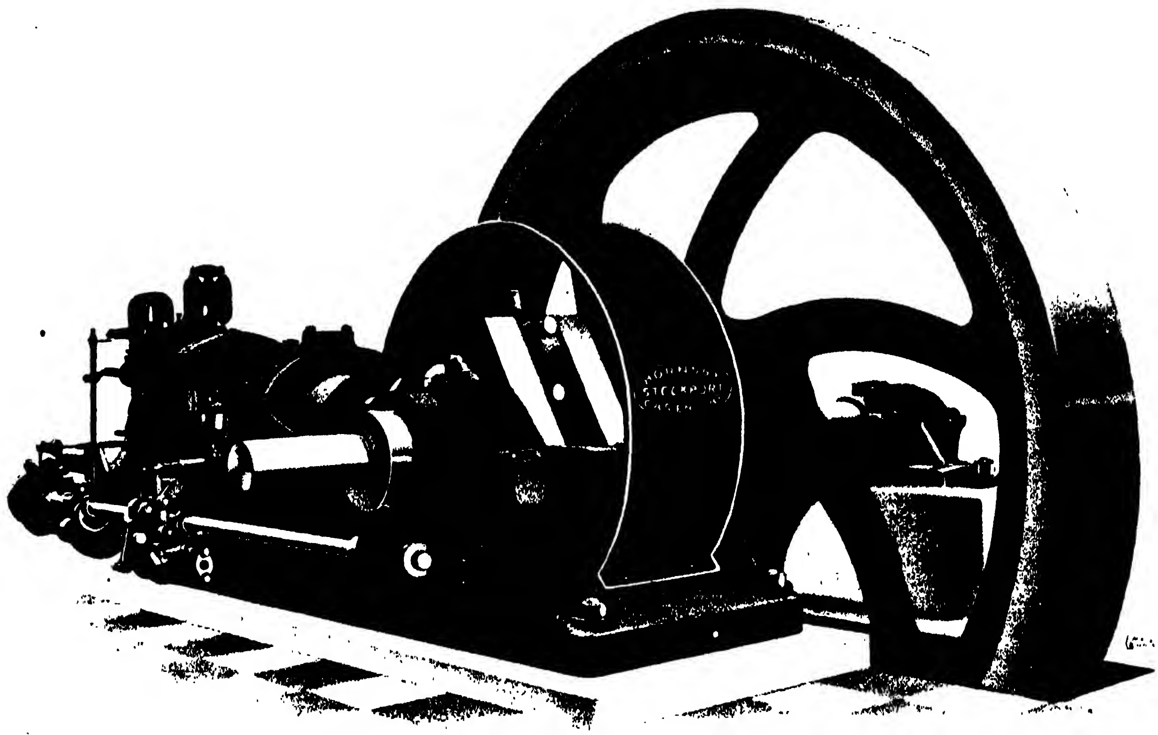


Fig. 336 Hornsby-Stockport Gas Engine fitted with specially heavy flywheel for direct Electric Lighting

more, and the quantity of lubricating oil used was small. Horizontal engines of the same type have been made with equally good results.

The Hornsby-Stockport Engine.—These engines were originally made by Andrew & Co., and were known in France as the Triomphe engine. Two modern examples of Hornsby-Stockport engines are given in figs. 335 and 336. The latter has a specially heavy flywheel for direct electric lighting, and the outer end of the shaft is supported on an extra bearing. Governors of a special vibrating weight type are fitted to the small engines of about 6 h.p., fig. 335, but centrifugal-ball governors are used for all larger sizes, which are also provided with self-starters of a compressed-air type. Small engines may be readily started by hand, and for the intermediate sizes a simple pump arrangement is recommended. Either tube or electric ignition may be provided, but magneto-electric ignition is supplied in all cases where suction gas is used.

To start an engine provided with a self starting gear, care must be taken to stop the engine with the connecting rod just above the centre and with the piston near the

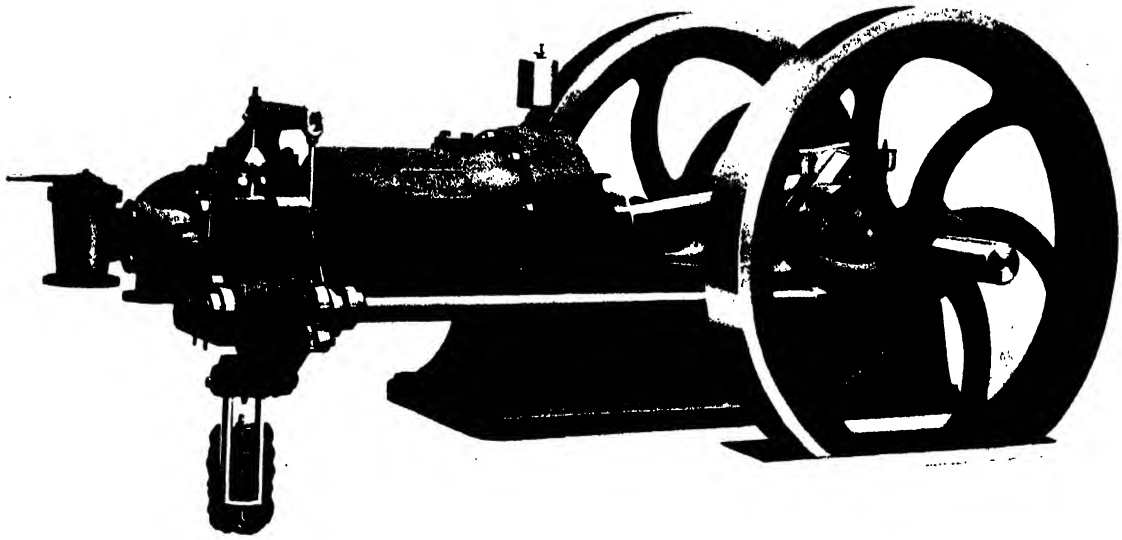


Fig. 337. - Fielding Gas Engine. 70 B.H.P. (with Suction Gas)

end of its stroke at the position of ignition. Gas is then admitted to the cylinder through a small valve held open by a light spring, and entering, as it does, under some pressure, a portion of the air in the cylinder is driven through another small spring-

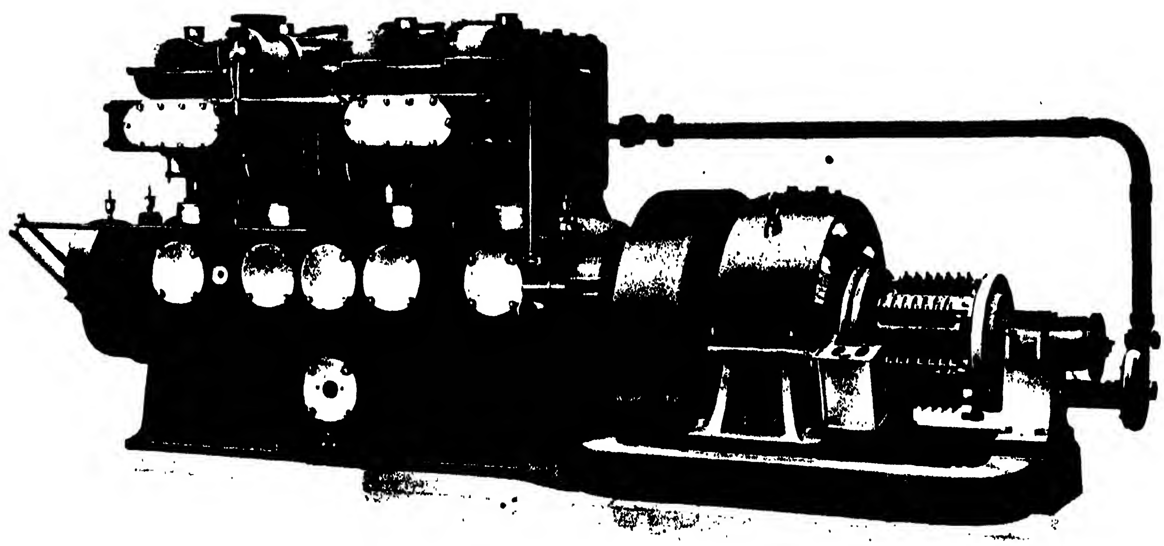


Fig. 338 Fielding Gas Engine. Vertical Enclosed Four-cylinder Type, 180 B.H.P.

controlled valve into a chamber communicating directly with the incandescent ignition tube. After a few moments some of the entering gas also passes through the upper valve into the ignition space, and when sufficient has passed to make an explosive mixture, ignition of the small charge takes place in contact with the tube or the electric spark.

The flame of the small charge in turn explodes the mixture in the cylinder, and the piston moves forward, driven by the force of the expanding gases. After the first stroke the working of the engine becomes automatic, the gas and air valves being controlled in the usual way from the cam shaft driven from the engine itself. Producer gas may also be used, in which case the consumption of anthracite is about 1¼ to 1¾ lb. per horse-power hour.

Fielding Engine.—Simplicity is the characteristic feature of the design of this engine. Two valves only are used, one of which alone is under pressure, and slide valves are dispensed with, even in the small-power vertical types. One of the valves, which is double-acting, controls both the admission and the exhaust, and the other the gas. A single cam and double lever controls the two valves and constitutes the whole of the gear. The action, which is based on the Otto four-stroke cycle, is as follows: when the piston commences its return stroke after the explosion, the exhaust valve is lifted by the motion of the valve lever, and the burnt gases are expelled; at the end of this stroke the valve is lifted still further, so as to close the exhaust and at the same time to open a lower aperture, through which the new charge is sucked into the cylinder; when the piston reaches the end of the admission stroke the cam lever releases the valve, which is forced noiselessly back upon its seat by a light spring, and the compression stroke then commences. The double lift of the valve is obtained by means of a single cam provided with two stepped projections, which come successively into contact with the end of the valve lever, and the form of the valve, which is the only one subjected to the high pressure of the exploded gases, is such as to ensure complete gas tightness and freedom from distortion. The second valve, placed before the first, has merely to admit the gas, and is therefore easily worked. It is controlled by the second lever, the displacement of which is regulated by the governor in accordance with the speed variations of the engine on the "hit and miss" principle. When running at the normal speed the governor holds in a definite position an oscillating pallet, which comes into contact with an inclined surface at the end of the gas-admission lever, and at each oscillation depresses it. When the speed increases beyond a predetermined point the action of the governor raises the pallet against the retaining force of its spring and causes it to miss the end of the valve lever, which thus fails to open and admit the charge of gas for the next stroke. Owing to the frictionless nature of the gear this system of governing is very sensitive, and a constant speed of rotation is thereby ensured. Compressed air is used for starting large units up to 350 h.p., the supply of air being derived from a reservoir which is charged during the running of the engine. Rich town gas or "poor" producer gases may equally well be burned in the Fielding engine. Fig. 337 illustrates a 70-b.h.p. engine designed for use with suction gas, and fig. 338 a four-cylinder Fielding gas engine of 180 b.h.p. directly coupled to a lighting dynamo. The engine is entirely enclosed, and is designed for use in conjunction with a suction-gas plant.

Niel Engine.—A novel type of conical rotating valve is employed in the Niel engine for controlling the whole distribution of the charge and the exhaust. By means of suitable gearing the valve is made to rotate once for every two revolutions of the crank, and during this period it effects successively the admission of the mixture to

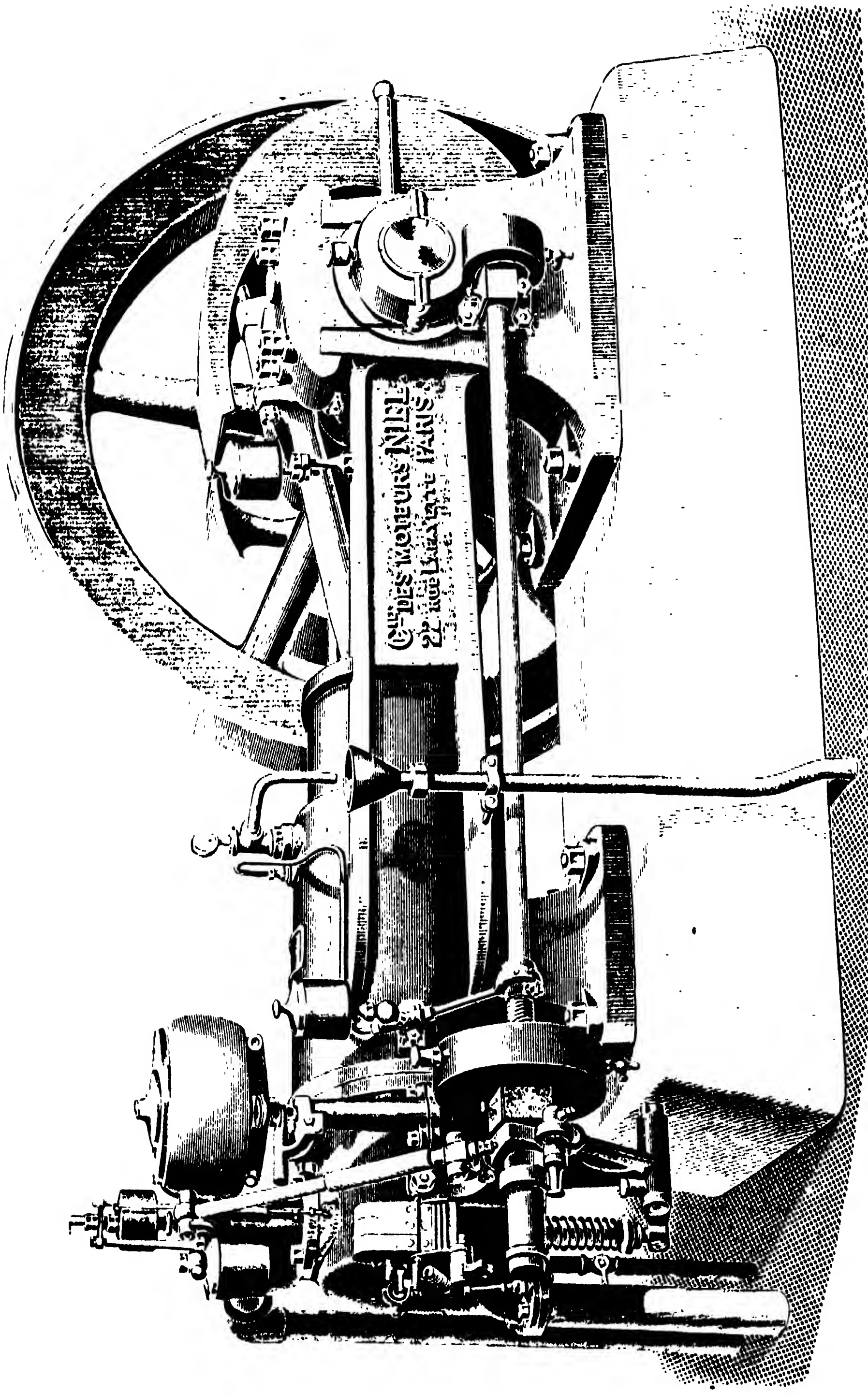


Fig. 339.—External View of Niel Engine

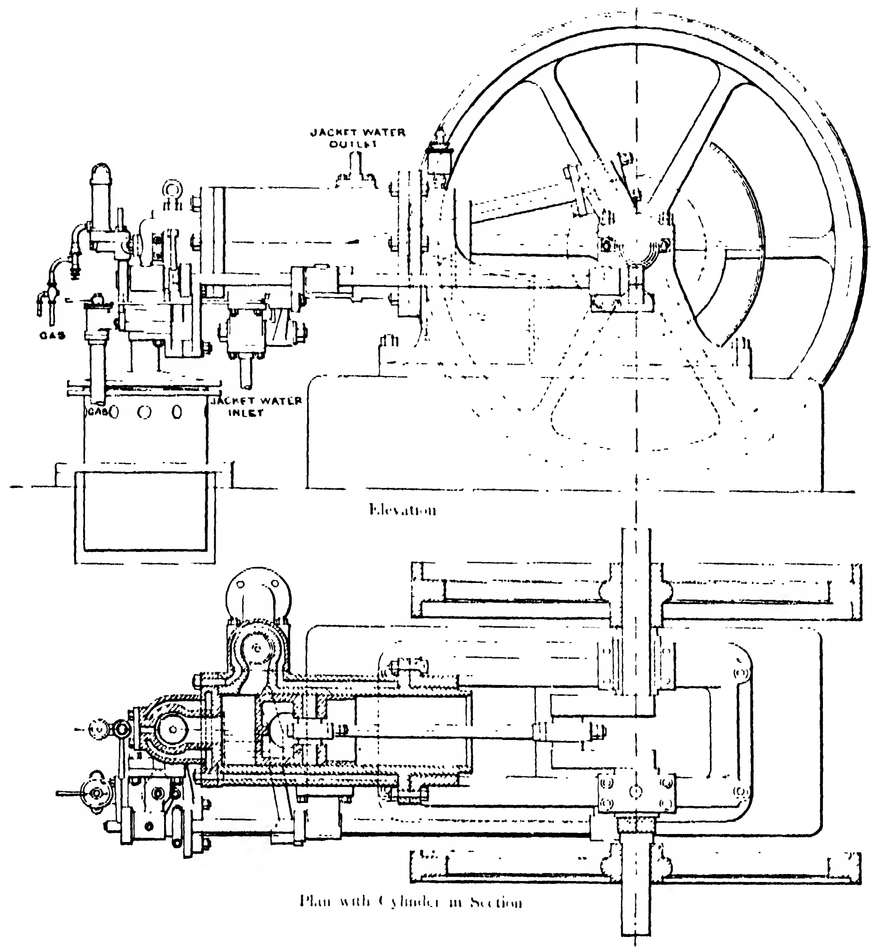


Fig. 340.—Niel Engine showing Conical-Valve Arrangement

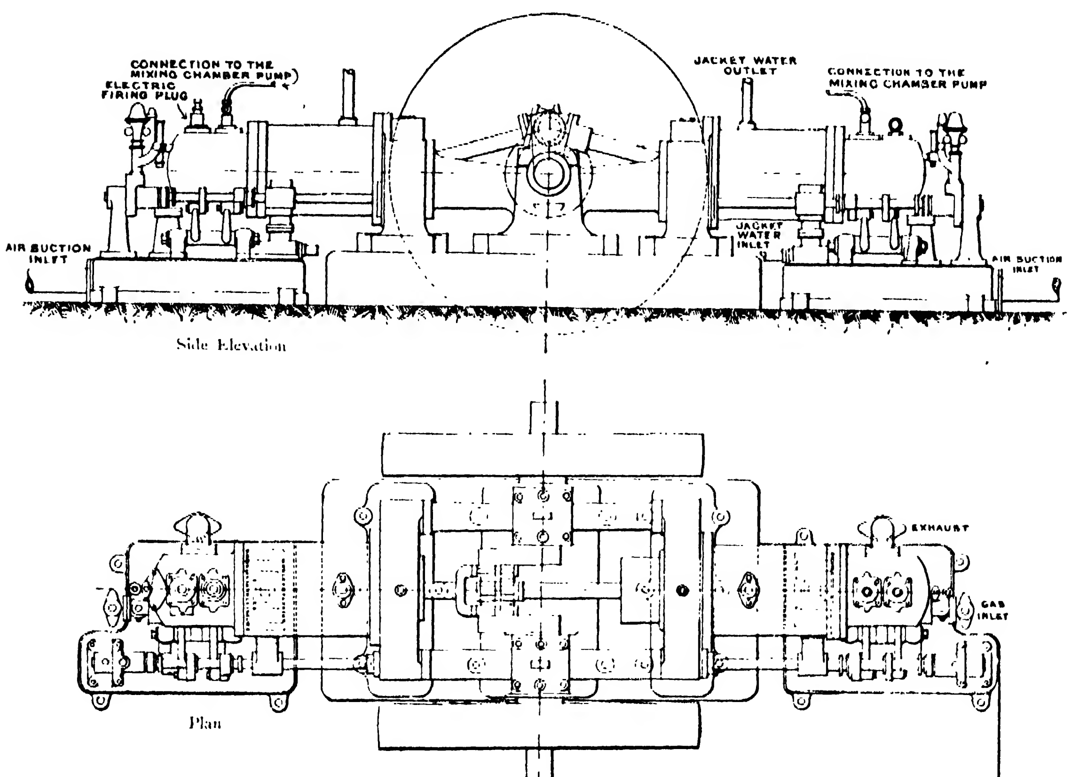


Fig. 341. Double Niel Gas Engine of 120 H.P.

the cylinder, the ignition, compression, and expansion, and finally the exhaust of the burnt gases. An ingenious arrangement ensures sufficient gas tightness and prevents the valve from sticking. Although the four-stroke cycle is used, suction only takes place during two-thirds of the forward stroke, and the quantity of gas drawn in is therefore less than the volume of the cylinder. From this there results a certain economy, as the expansion is not so great and the compression is less. The incandescent tube arrangement introduced by Leo Funck in 1883 is adopted for the ignition.

Fig. 340 shows an elevation and a sectional plan of the conical-valve type of Niel engine, while figs. 341 and 342 illustrate a large 120-h.p. engine fitted with ordinary lift valves, which are shown in section in fig. 342.

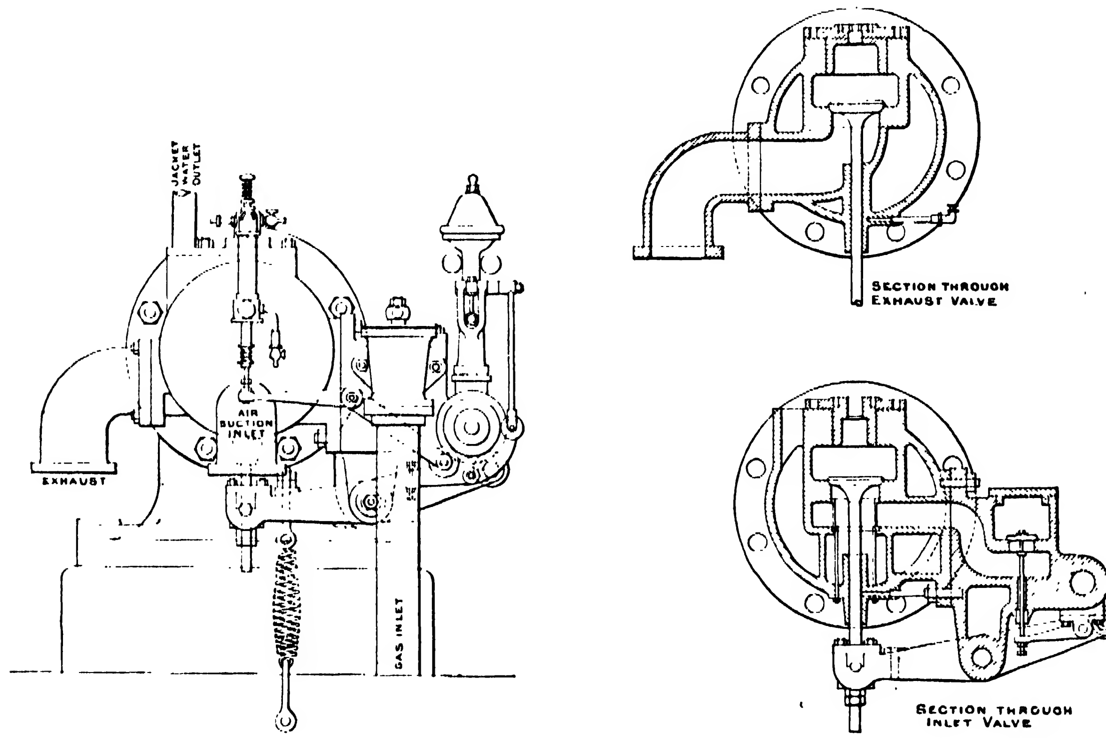


Fig. 342.—Valve Arrangement of Niel Engine

The Martini, Sombart, Adam, Roger, and Kientzy Engines.—Although built by different makers these engines, which work on the Otto cycle, differ from one another in unimportant details only. Considering also the absence of any novel features it is unnecessary here to do more than mention their names.

Lablin Engine. Mr. Lablin of Nantes devised what may be considered as the gas type of the Brotherhood steam engine, that is to say, an engine combining the greatest possible power with the minimum weight and size. To quote Mr. Lablin's words, the engine was devised with a view to increasing the "dynamical density" of the gas engine, and he so far succeeded in being able to construct engines of half a horse power weighing only 88 lb. and engines of 8 h.p. weighing less than $3\frac{1}{2}$ tons with a consumption of 35 cu. ft. of town gas or 1 lb. of gasolene. The engine works on the Otto cycle but three cylinders arranged radially around one crank are used, and the system of working is such that an explosion takes place in each cylinder successively, there being thus three driving strokes per revolution of the common crank. A flywheel of the minimum proportions may then be used, as the driving effort is

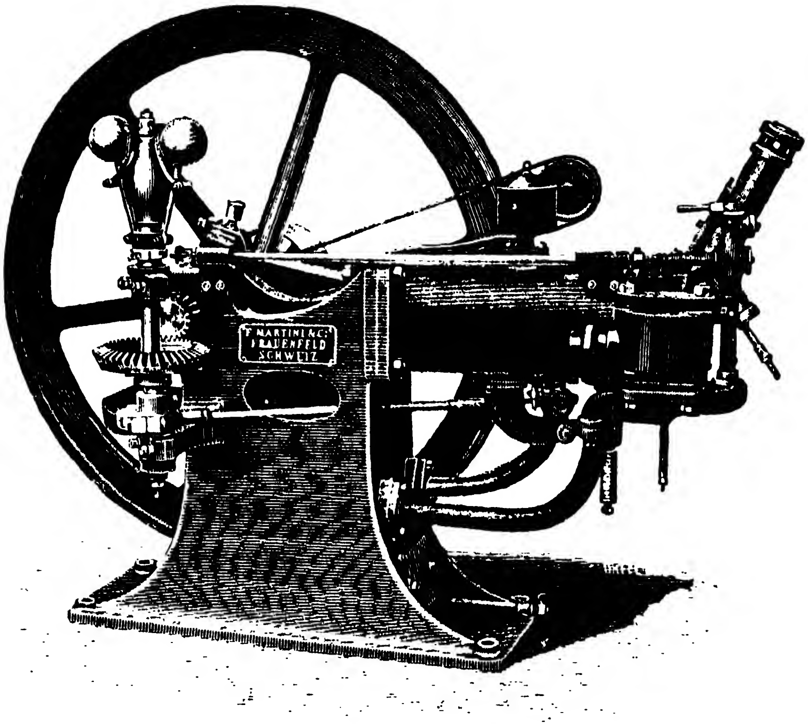


Fig. 343.—Martini Engine

practically uniform. When the crank occupies the position shown in fig. 344, and when the direction of motion is that indicated by the arrow, explosion occurs in cylinder A, and its piston drives the crank. Exhaust of the waste gases commences from cylinder B,

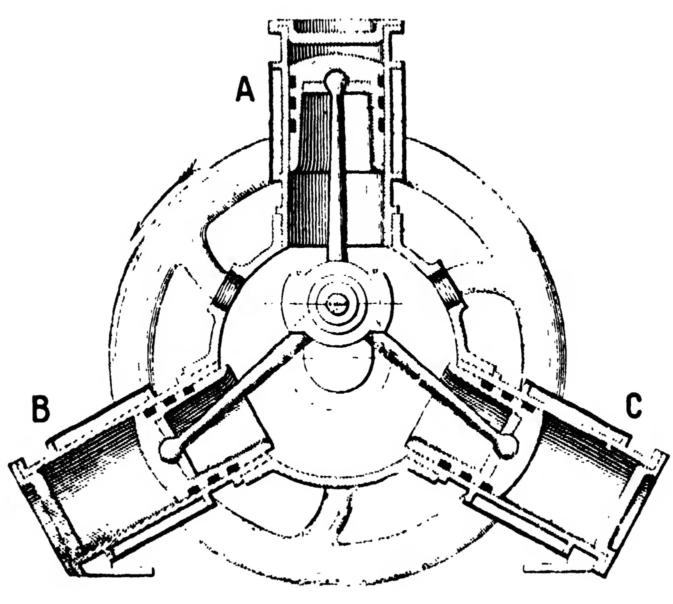


Fig. 344.—Lablin Three-cylinder Engine

and the piston of C finishes the suction stroke preparatory to the compression of the mixture. Between the end of one driving period and the commencement of the next the interval does not exceed one-sixth of a revolution. Firing of the mixture may be effected either by the use of a heated ignition tube or by an electric spark, the former

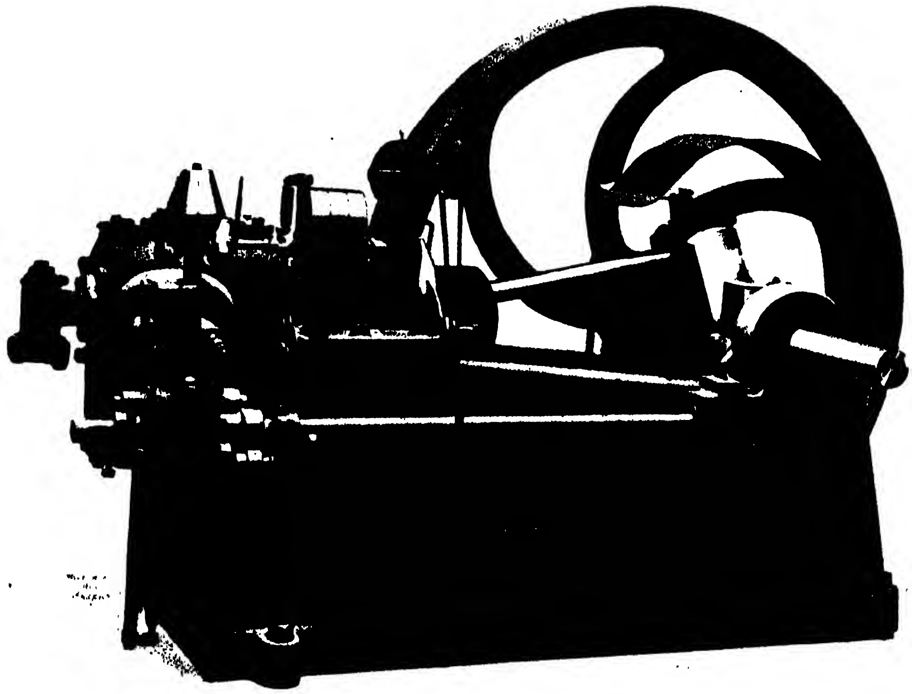


Fig. 345.—Small type of Campbell Gas Engine

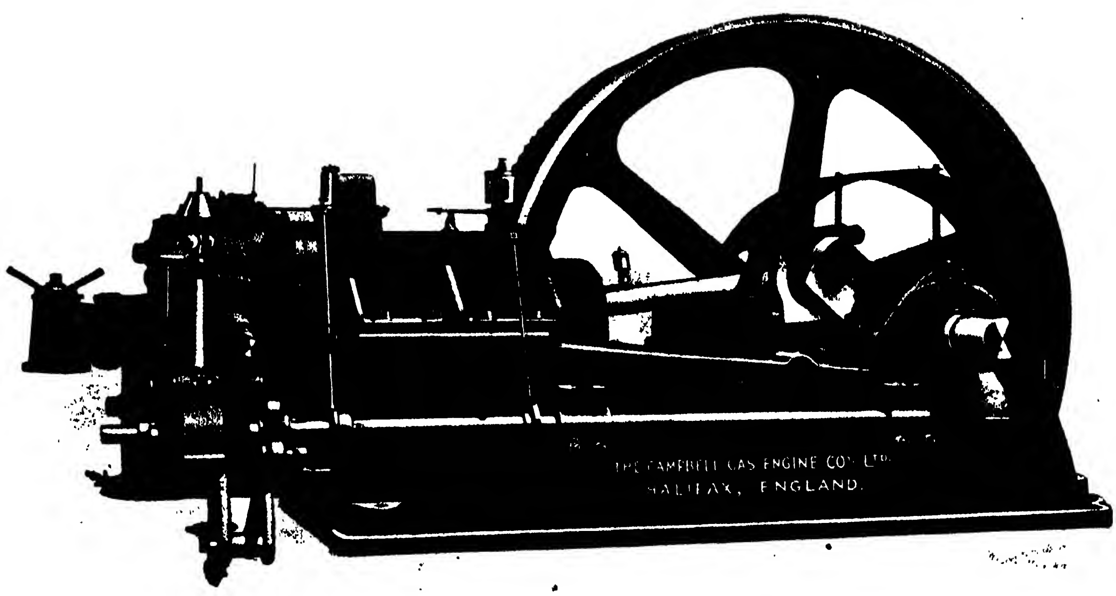


Fig. 346.—Campbell Gas Engine of 70 to 80 B.H.P. with Producer Gas

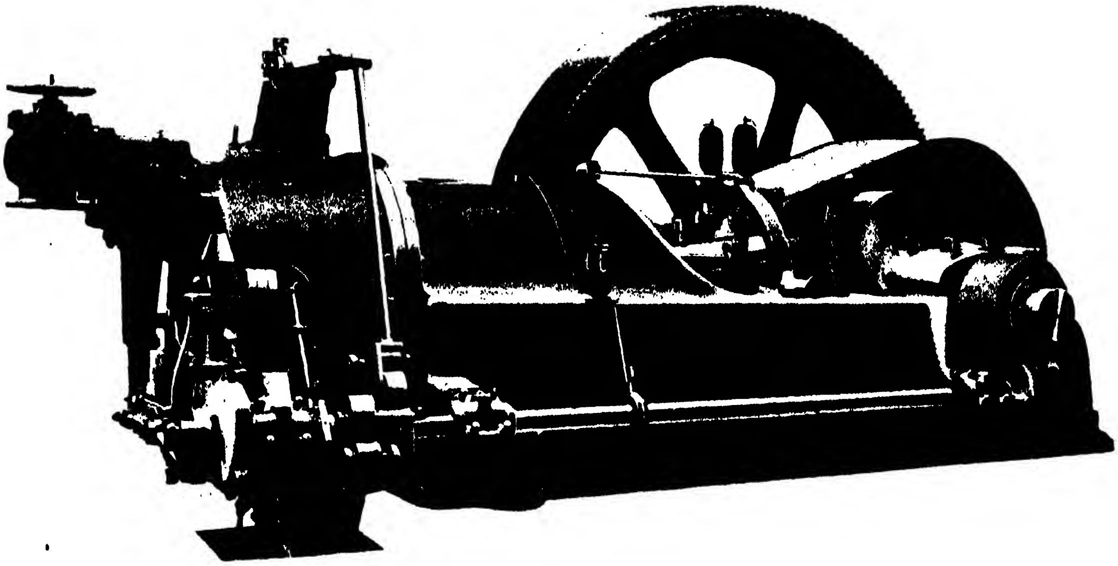


Fig. 347.—Campbell Gas Engine 90 to 100 B.H.P.

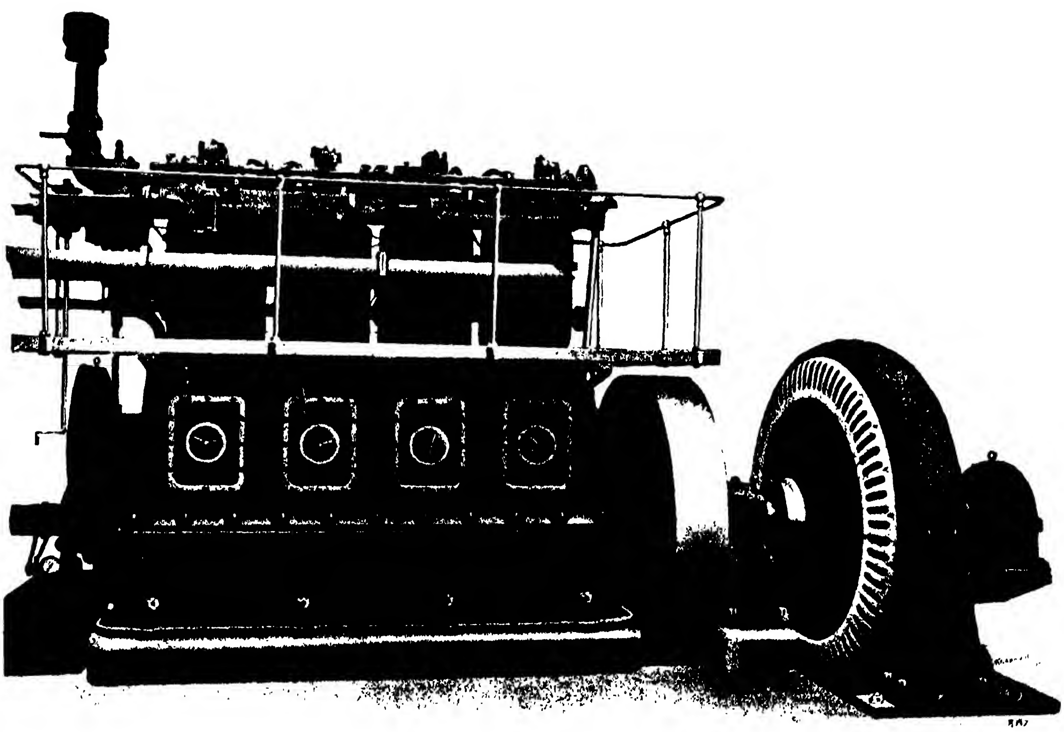


Fig. 348.—Campbell Vertical Four-cylinder Gas Engine Type for B.H. Powers of 100 to 750

method being usually adopted when the working substance is gas, and the latter for oil vapours. The speed of the engine was controlled by a centrifugal governor which acted upon the gas-admission valve.

Campbell Engine. Several types of Campbell engines, which in principle are based upon the Otto engine, are illustrated in figs. 345 to 348. In the horizontal types a horizontal shaft placed at the side of the engine at right angles to the crank shaft receives its motion from the latter through a pair of helical gears. On the opposite end of the side shaft are arranged several cams, which control four valves for the

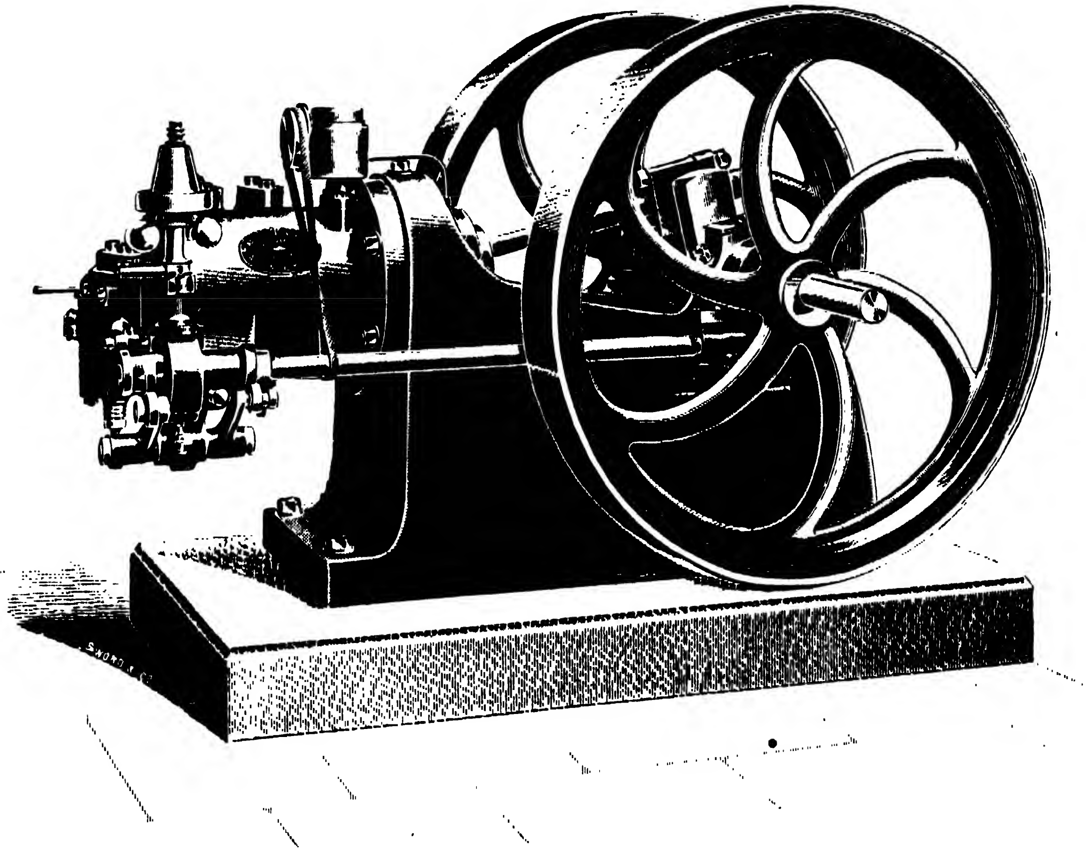


Fig. 349.—National Gas Engine

admission of the air and gas and for ignition and exhaust. A tube heated to cherry red by an internal gas flame is used for the ignition when town gas is consumed, but it is customary to supply magneto-electric ignition whenever the engine is intended to use producer gas. In all the engines of more than 70 b.h.p. not only the cylinder but also the piston and the exhaust valves and covers are water cooled. Fig. 345 illustrates the small sizes of engines of from 4 to 11 b.h.p. using producer gas, while two larger types of 70 to 80 and 90 to 100 b.h.p. are shown in figs. 346 and 347. The four-cylinder vertical type of from 100 to 750 h.p. is shown in fig. 348.

The National Engine. Gas engines are built by the National Company in all sizes from the smallest of 1 h.p. to the largest units burning producer gas. Petrol engines are built by the same company for effective powers of from 1 to 10 h.p. All of these engines, whether gas or oil, are provided with two large well-balanced flywheels which

ensure uniformity of the rotational motion; but this uniformity is also partly due to the use of a novel form of centrifugal governor which materially reduces the consumption. Fig. 349 illustrates the outward appearance of the gas engine, and also with minor differences that of the oil engines, which are provided in addition with a vaporizer and

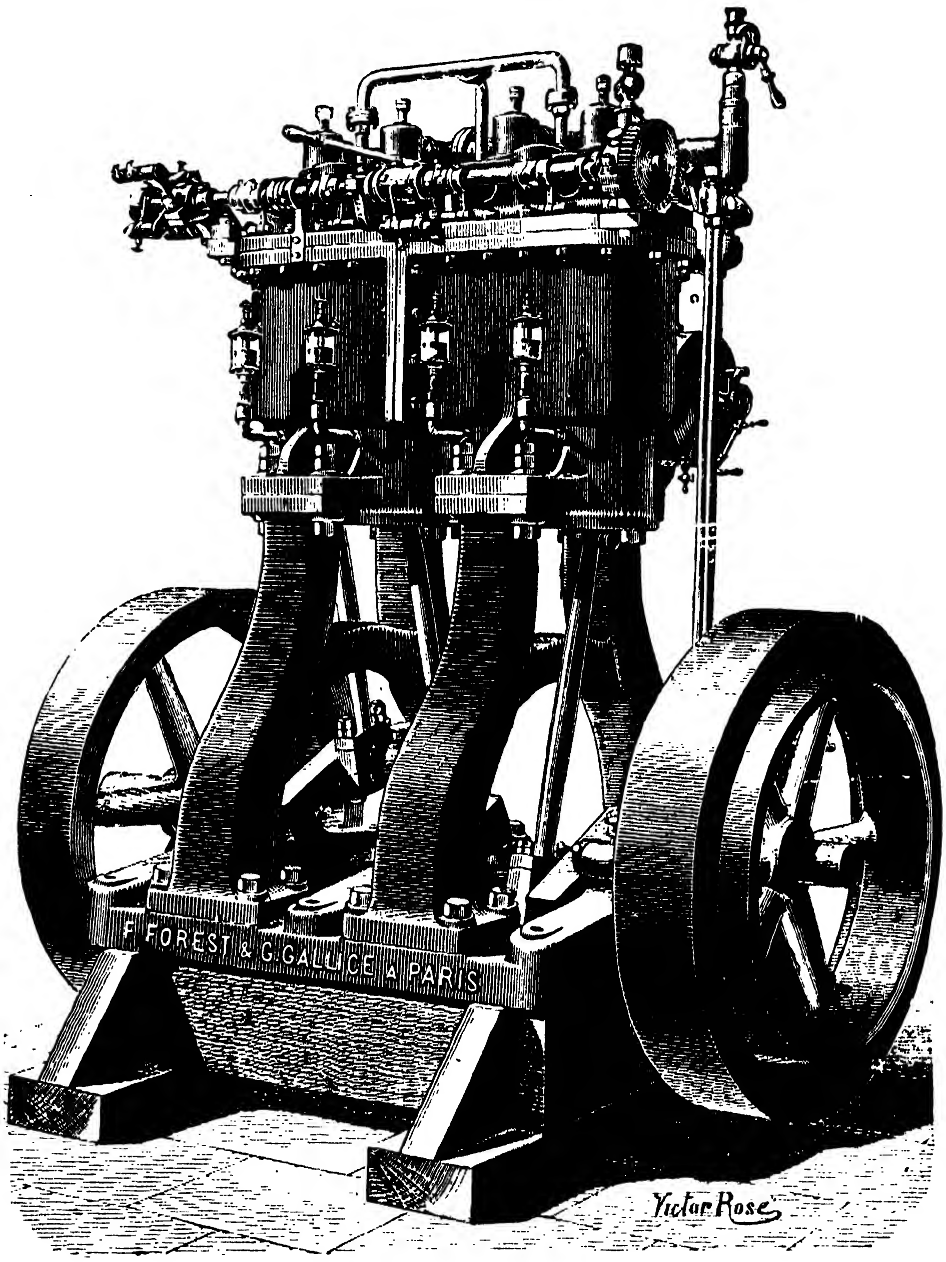


Fig. 350. Forest Gas Engine

lamp placed at the front and with an oil reservoir immediately above the cylinder. Special attention has been devoted to the reduction of the number of the parts, and the result has been a design of the simplest possible description. One cylinder alone is used for all engines of less than 50 h.p. The starting gear has been much simplified, and the ignition arrangements are such that miss-fires rarely occur. Much skilled attention is not required to keep the engine in good condition, and the lubrication is for the greater part done automatically.

Forest Engine. Reference has already been made to the two-cycle' non-compression engine first introduced by Mr. Forest, who has made the gas engine the subject of considerable research work. Two other interesting types of Forest engines, working on the four-stroke cycle, have also been introduced with considerable success. In one of these types, which is of a specially compact design, the cylinders are open at both ends, and each contains two pistons, between which the charge is introduced. On the explosion of the mixture the pistons are driven in opposite directions, and their motions are transmitted to the crank, directly in the one case by means of connecting

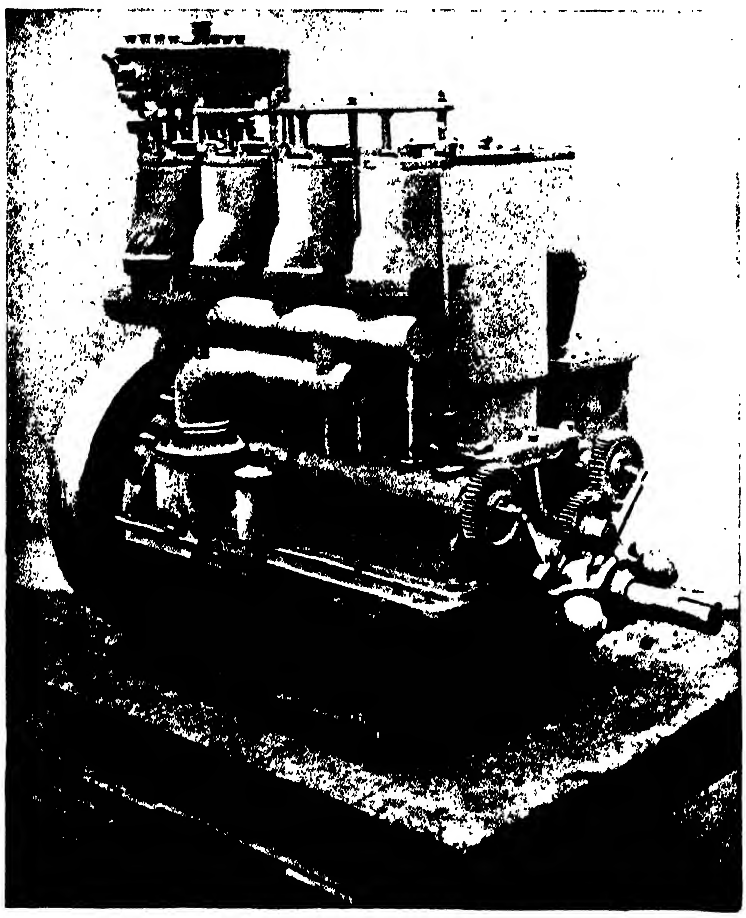


Fig. 351.—Forest Petrol Launch Engine. Inlet Valve Side.

rods, and indirectly in the other through side levers. The second type, illustrated in fig. 350, has two or more cylinders bolted together, and carried on columns over the crank shaft. By the use of two cylinders the regularity of the running is much improved, as one driving impulse is obtained during each half revolution. For the driving of launches, Mr. Forest, in conjunction with Mr. Gallice, has succeeded in producing a very successful type of petrol engine, which has been adopted by the French government, and fitted by them to numerous boats of various sizes. By an ingenious and simple arrangement of the cams on the valve shaft, which controls the admission and exhaust, the motion of the engine may be reversed instantly and at will, which, for marine work, is a most important feature. Figs. 351 and 352 are external views of the front and back of one of these launch engines.

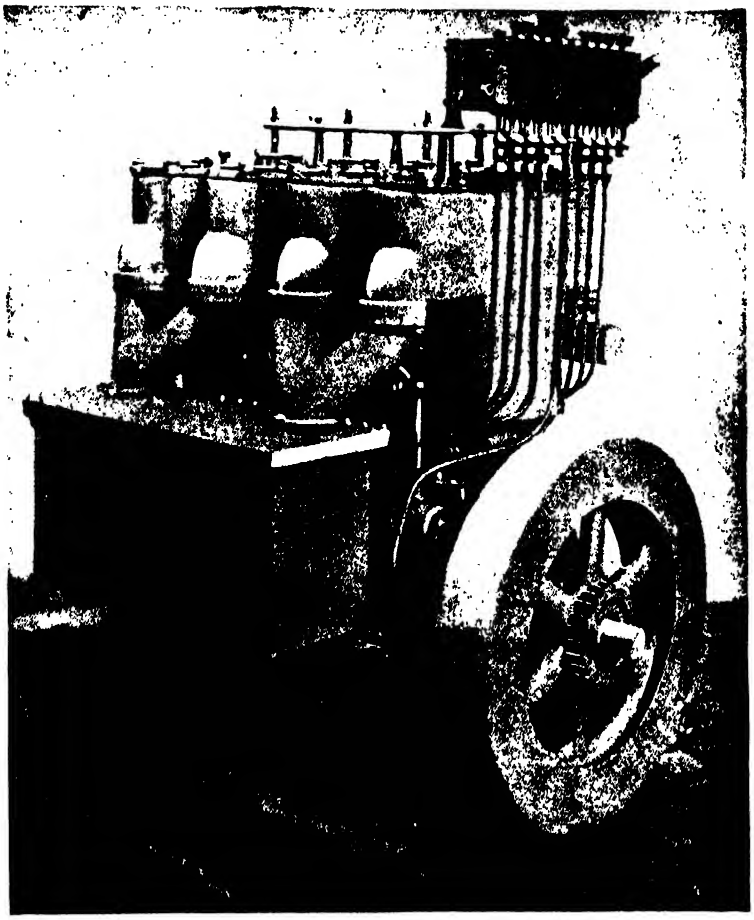


Fig. 352. Forest Petrol Launch Engine. Exhaust Valve Side

Atkinson Engine. Several ingenious arrangements have been devised by Atkinson with the intention of increasing the expansion obtainable in the ordinary Otto arrangement. Atkinson's first engine, exhibited in 1885, was known as the Differential gas engine, and consisted of a single cylinder, having two opposed pistons connected to the crank through a system of levers and links. This arrangement was abandoned in favour of a single cylinder and piston engine, but the long-expansion and short-compression features were retained, the desired motion being effected by means of the system of levers shown diagrammatically for one position in fig. 353.

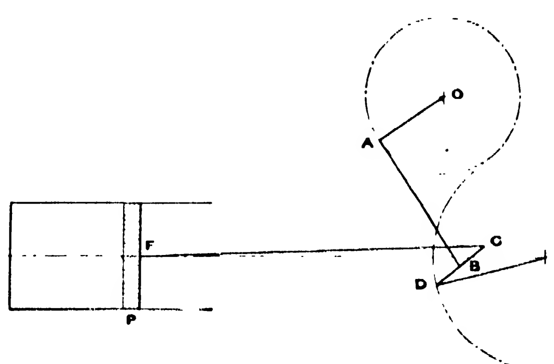


Fig. 353 Atkinson Link Arrangement giving one Impulse Stroke per Revolution

Noël Engines.—These engines, which are built in France, at Provins, have the merit of great simplicity. Ordinary lift valves take the place of slides, and in the case of engines of from $\frac{1}{4}$ to 2 h.p., the use of a water jacket is dispensed with. Both horizontal and vertical types are built, and the engines work equally well on either town gas or carburetted air. When using the latter mixture the vaporizer is generally enclosed in the framework supporting

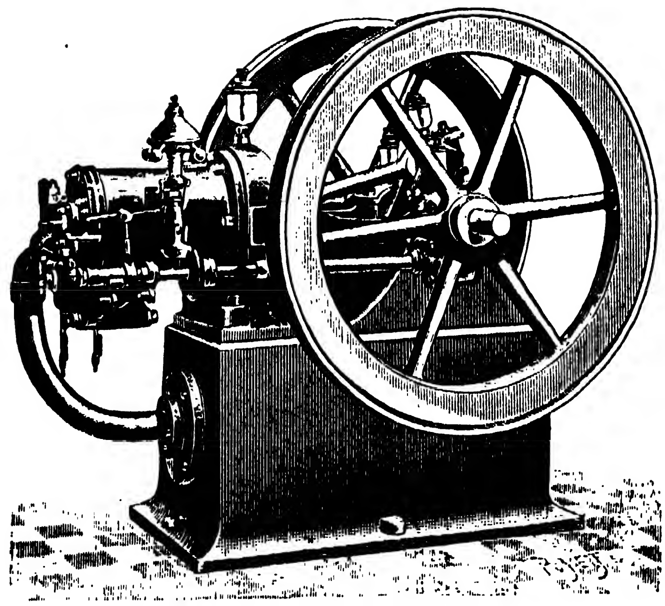


Fig. 354.—Charon Engine

the cylinder. A consumption of 32 cu. ft. of gas per brake-horse-power hour, or 1 pint of gasolene, is guaranteed by the makers.

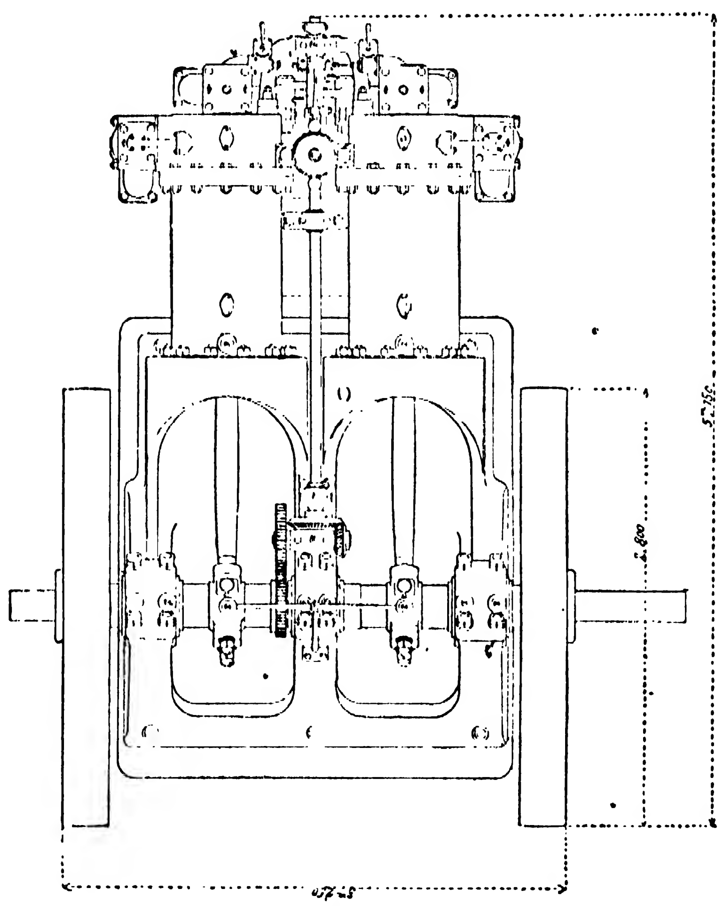


Fig. 355.—Plan of Two-cylinder 160-H.P. Charon Engine

Tenting Engine.—The Tenting engine is of the horizontal type, and has the cylinder cooled by air instead of water. A battery and induction coil supply the electric

spark for the ignition, and a governor of the "hit and miss" type controls the speed by acting on the exhaust. When the speed exceeds a certain limit the governor causes the exhaust valve to remain closed, and thus prevents the escape of the waste gases and the suction of the following charges, until the engine speed again falls to the normal.

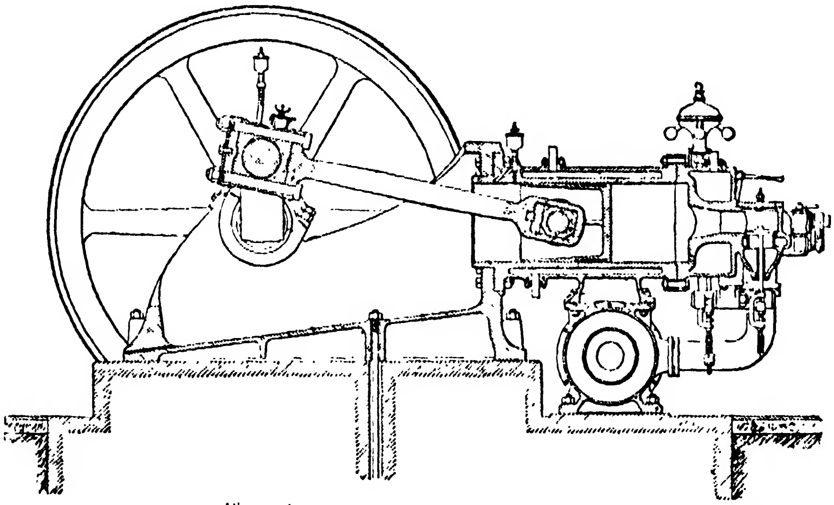


Fig. 356. Section of 100-H.P. Charon Engine

On account of the simplicity of the design, and the fewness of the parts, Tenting engines of low powers have been very extensively applied to many different purposes, and for launches or similar work a vertical type designed to burn oil vapour is constructed.

Charon Engine. -Mr. Charon sought to prolong the duration of the expansion by means less complicated than those devised in the first instance by Mr. Atkinson. His gear consists of a shaft having a double stepped cam controlled from the governor.

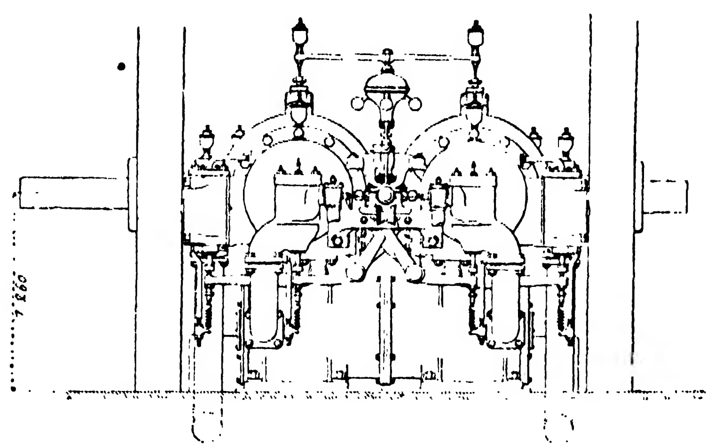


Fig. 357.—End View of 100-H.P. Charon Engine

One half of the double cam operates the admission, and the other half a special valve, through which a portion of the explosive mixture is driven into a large pipe or reservoir during the compression. The compression of the portion of the charge in the cylinder is thus reduced, while the expansion is more complete, and is, at the same time, entirely under the control of the governor. As a result of this increased expansion a very satisfactory consumption was obtained.

Letombe Engine.—Messrs. Mollet-Fontaine, of Lille, build the Letombe engine, which embodies several novel and interesting features. The engine is double-acting,

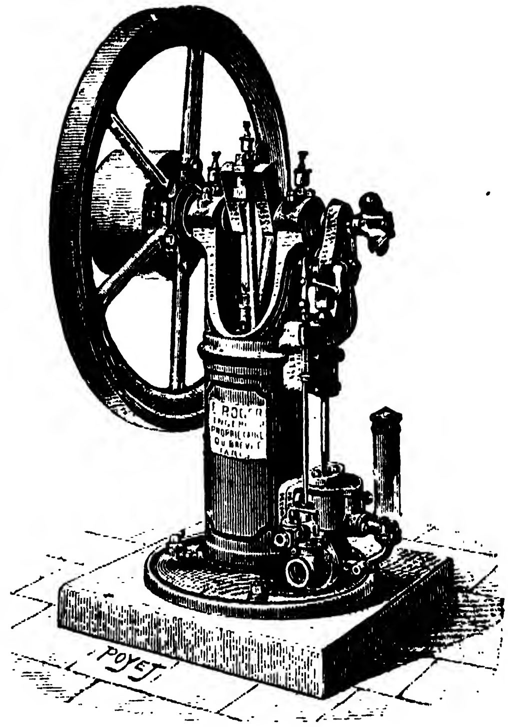


Fig. 358. Roger Vertical Engine, 2 H.P.

and the stages in the action on the two faces of the piston follow one another at intervals of half a revolution, so that during each revolution of the shaft there is one driving

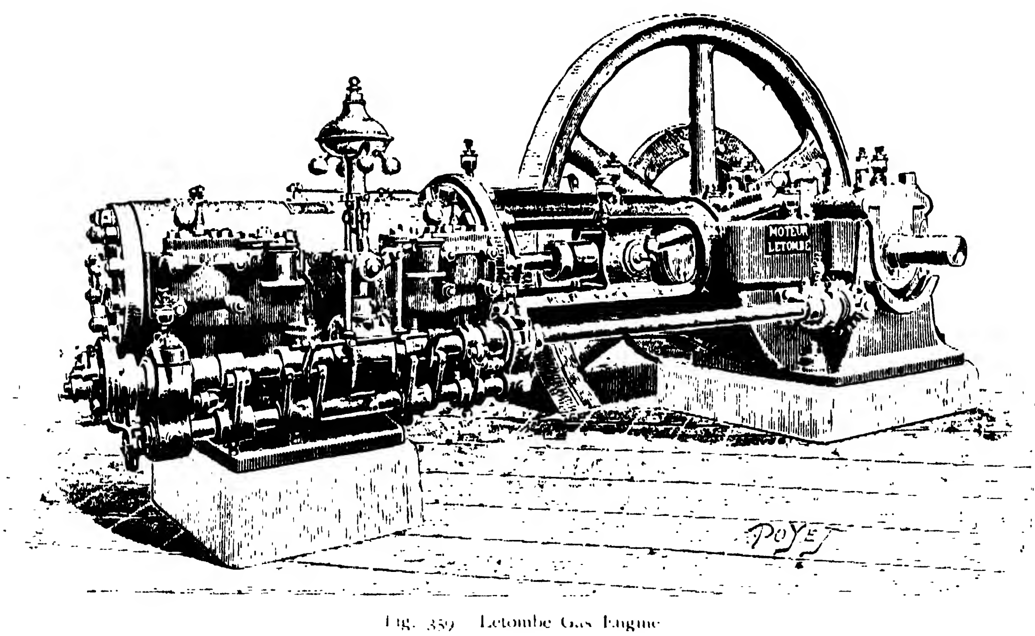


Fig. 359. Letombe Gas Engine.

impulse. As a result of this the uniformity of the motion is equal to that obtained with two-stroke cycle engines, and the economy is also increased to an important degree by the lengthening of the expansion, as in the Charon engine.

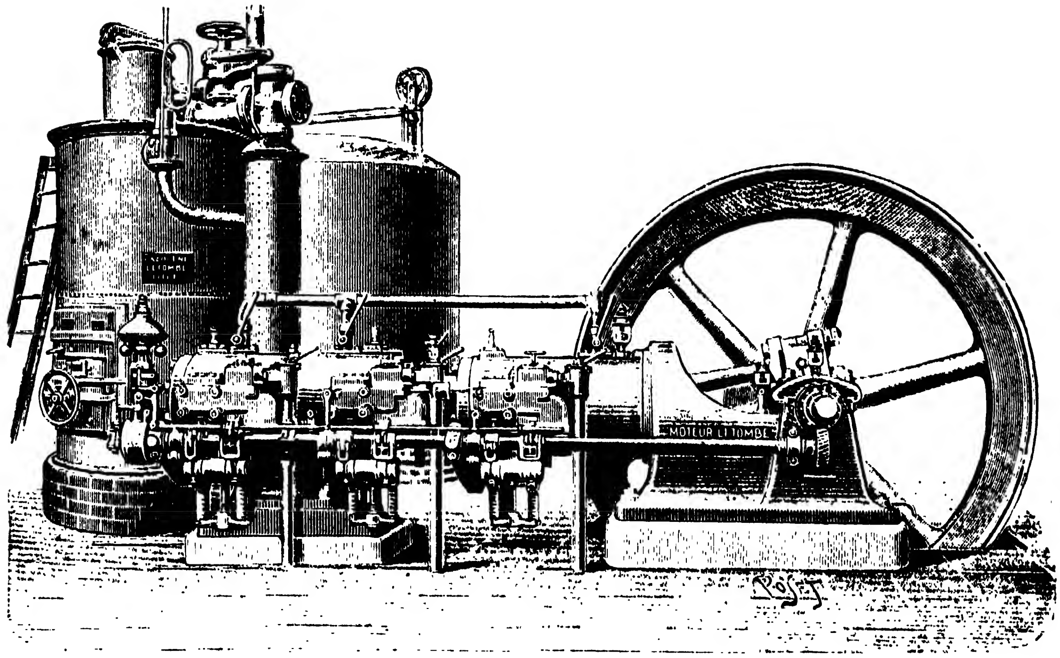


Fig. 390.—Letombe Gas Engine consuming Producer Gas.

Ragot Gas Engine. In 1878 Mr. Ragot exhibited in Paris a petroleum engine which obtained a certain success. Encouraged by these results the inventor developed his ideas on the same lines, and in 1885 introduced a horizontal four-cycle engine of

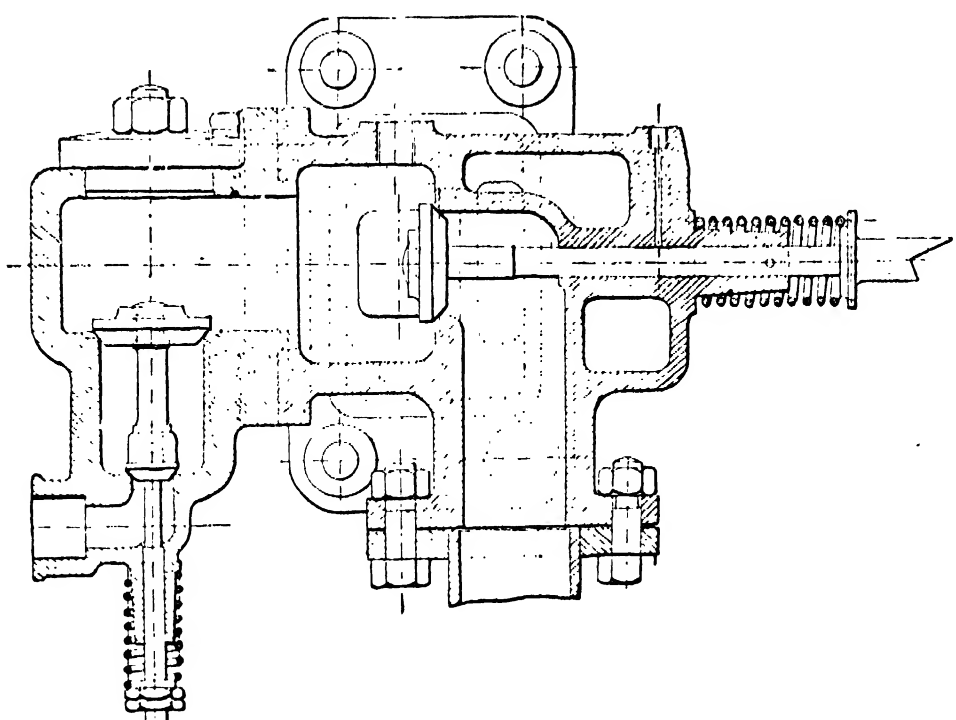


Fig. 391.—Valves of Ragot Engine

very simple design and reasonably good economy. A governing arrangement which controls the speed on the Koerting system by closing the exhaust valve has been adopted, and the firing of the charge is done by means of a heated gas tube. From the illustra-

tion (fig. 362) it will be seen that the piston acts directly on the crank without the use of a piston rod, and that the cylinder is cooled by the circulation of air in contact with metal vanes cast on the outside of its walls.

Crossley Gas Engine. The Crossley gas engine is the result of many years of experience and experiment, and is manufactured by Messrs. Crossley Bros., of Manchester, in a great variety of sizes, of which several are illustrated.

Fig. 363 shows the smallest size of $1\frac{1}{4}$ to $2\frac{1}{2}$ b.h.p. suitable for town gas, and the ignition is effected by the customary tube arrangement. A larger, 12-b.h.p. size, for lighting purposes is shown in fig. 364, and a still larger, 30- to 40-b.h.p. engine, in fig. 365.

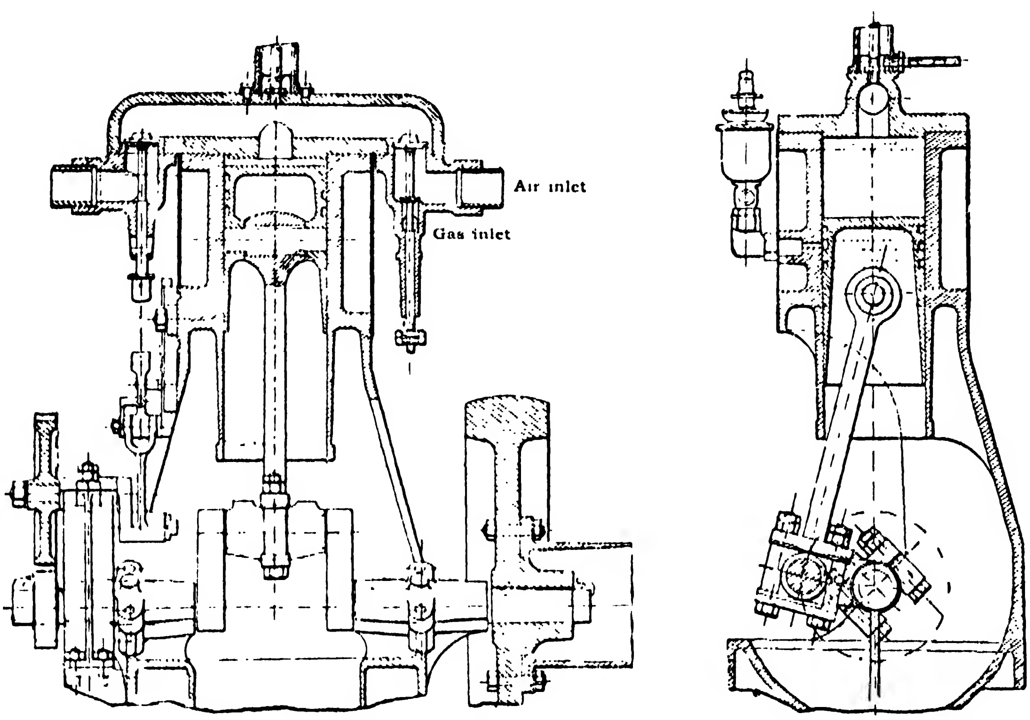


Fig. 362.—Side and Front Section of Ragot Engine

Suction gas may be used in the larger engines, but in such cases magneto-ignition arrangements are provided.

Westinghouse Gas Engine.—A section through the cylinder and essential parts of a single-acting Westinghouse engine is given in fig. 366, and a general view of a 240-b.h.p. vertical tandem four-cylinder engine is given in fig. 367.

From the section, fig. 366, which illustrates either the two-cylinder or three-cylinder arrangement, it will be seen that the valves are operated from the cam shaft c s, and that the action is based upon the Otto cycle. There is therefore one impulse per revolution in the two-cylinder engine type, and one per stroke in the four-cylinder arrangement, fig. 367.

Water jackets are provided around the parts subjected to the high temperature of the exhaust, and the water chamber is carried around the stem of the exhaust valve in engines of over 100 horse power.

High-tension electric ignition is provided, and the current is supplied by a small charging dynamo driven from the engine.

To start the engine compressed air is admitted during each stroke to one of the cylinders until an explosion of the charge in one of the other cylinders takes place, when the compressed-air supply is cut off from the first cylinder, and the mixture supplied instead.

During the running of the engine a small direct-driven compresser charges a reservoir with compressed air for restarting purposes, and in the case of large installations separately-driven compressers are used.

With these brief descriptions this section must now be concluded, as it is impossible in the limited space to describe all of the many interesting gas engines that have been

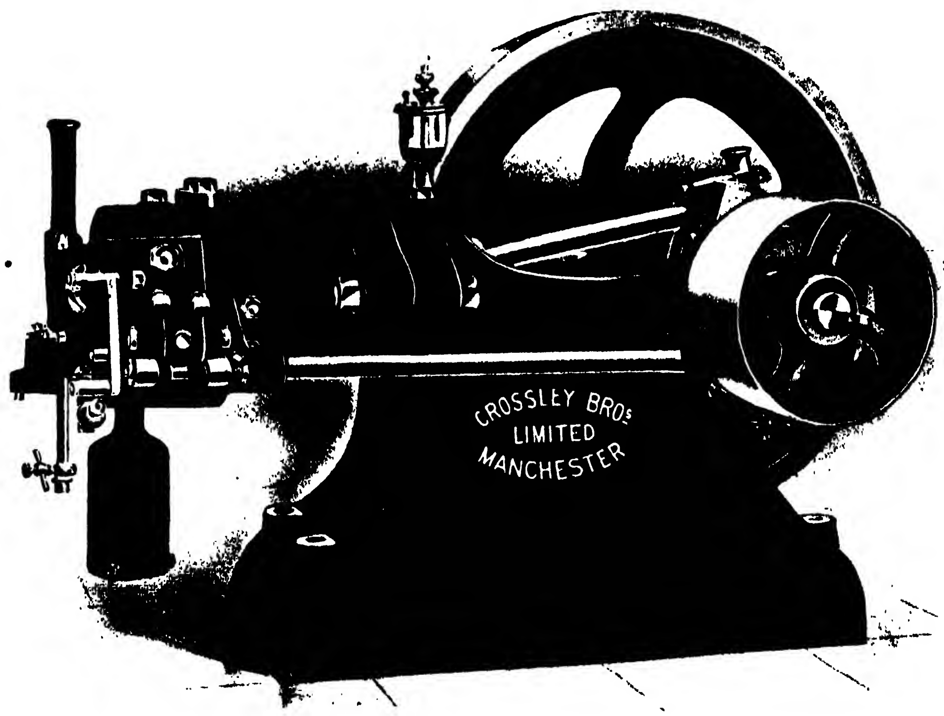


Fig. 363.—Crossley Horizontal Gas Engine—Smallest Sizes, 1¾ and 2½ B.H.P.

introduced in this and other countries, but before proceeding to the consideration of carburetted-air engines some mention must be made of two types which work upon a six-stage cycle. Special arrangements are provided in engines of this kind, not only for exhausting the burnt gases in the usual way after the working stroke, but also for expelling any residual gases by means of a blast of air. After the fourth stroke of the ordinary Otto cycle a blast of pure air is drawn into the cylinder and finally expelled.

The Griffin System.—In engines of this cycle there are two explosions every three strokes, but since the Griffin engine is double acting, one impulse is given to the piston every revolution and a half. The successive stages are: (1) Aspiration of the gas and air mixture; (2) Compression; (3) Ignition, expansion, driving stroke; (4) Exhaust of the burnt gases; (5) Admission of air blast to complete the expulsion of the burnt gases; (6) Complete exhaust. Admission and ignition are controlled by

a slide valve, and the speed is regulated within small limits by means of a governor, which acts on the gas admission valve placed on the top of the cylinder. As the speed varies the governor suitably advances a triangular wedge, which holds the valve open for a longer or shorter period. Two valves worked by two cams at periods of 1½ revolution serve alternatively for the exhaust from the two sides of the piston. From official tests of a 12-h.p. engine the consumption is stated to be about 28 cu. ft. of gas per horse-power hour, and for regularity of working the engine was placed in the first class. Considering the six-stage system of working, this result is worthy of notice.

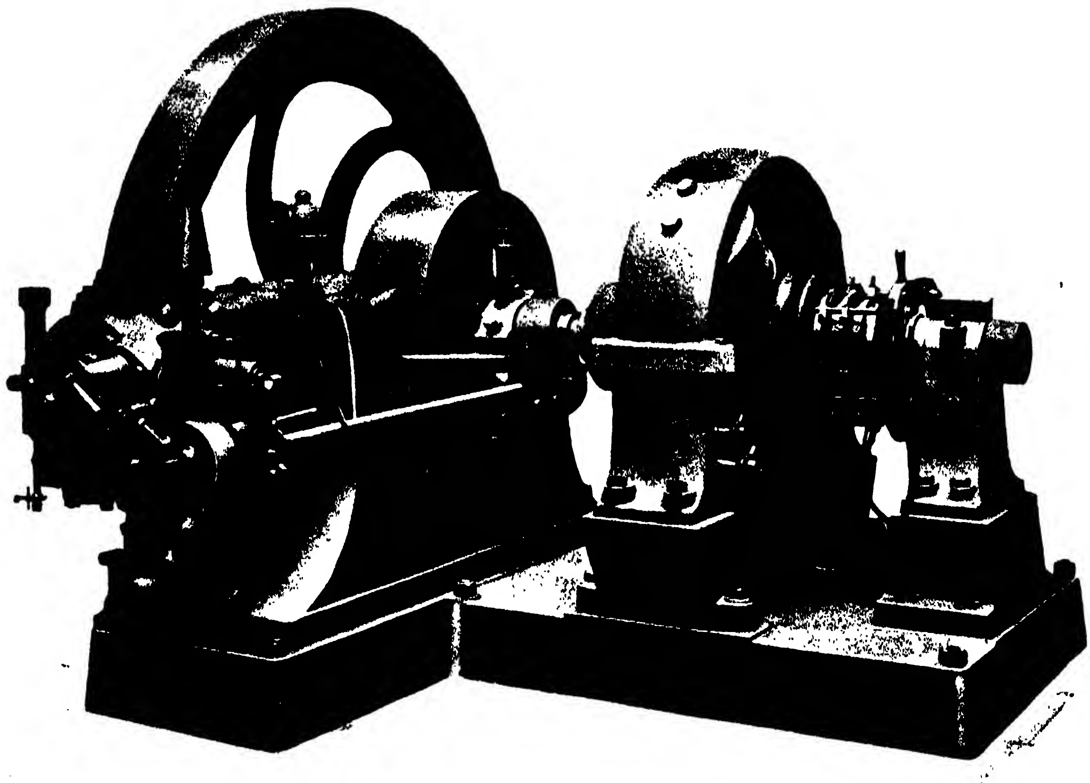


Fig. 364.—12-B.H.P. High-speed Crossley Gas Engine and Dynamo Direct-coupled

Rollason Engine.—This engine works upon the same cycle as the preceding one, but mechanically the arrangement resembles to a greater extent the Otto engine. An ingenious type of electrical governor acting upon the gas admission automatically proportions the supply to suit the power to be developed, and thus ensures a constant speed. For engines of from 20 to 100 h.p. a self-starting device is provided to dispense with the arduous labour of turning the engine by hand. By completely expelling the residual gases, as in the Griffin engine, it has been found possible to work with the very dilute mixtures which in the Otto engine resulted in miss-fires. The economy is satisfactory, and the engine has been generally applied in this country with successful results.

VAPORIZERS AND CARBURETTORS FOR OIL AND VAPOUR ENGINES

When cold air is saturated with the vapour of volatile oils, such as gasolene or light petroleum, having a mean density of about 0.65, there is formed a combustible mixture similar in its properties to lighting gas and equally suitable for the working of internal-combustion engines. Many arrangements have been devised for producing

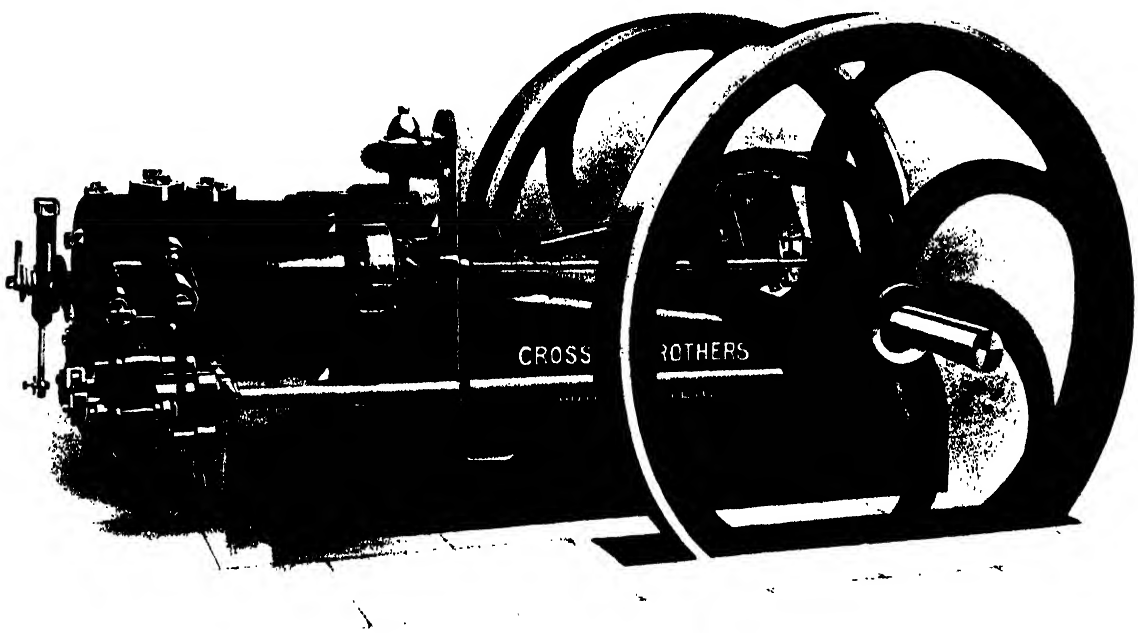


Fig. 305.—Crossley Gas Engine, 30 to 40 B.H.P.

the necessary carburation of the air, and certain of these which alone will be described have given good results in actual service.

Mille Gas System. In this system advantage is taken of the greater density of the spirit vapour compared with that of air. When the spirit is volatilized, the vapour as it forms falls to the bottom of the reservoir and sucks in a supply of air. The mixture of vapour and air then passes to the combustion chamber through a tube from the bottom of the reservoir, which is placed at a higher level. In one of the earliest arrangements, devised by Lafrong, the saturation was effected by means of a small hot-air engine; and in certain other systems, such as the Haerson, Pluyer and Muller of Birmingham, and the Eclipse and Phœbus engines, a small fan driven by a falling weight supplied the air required for the mixture. A species of Giffard injector is used for the same purpose in the Rouilli system. In this arrangement oil vaporized in a heated retort is passed through a nozzle into an expanding tube connected to the vapour reservoir. At the side of the combining nozzle is provided a lateral opening through which the air supply is sucked in by the rapid passage of the vapour through the narrow tapered nozzle.

Faignot System.—Air in this arrangement is supplied by a spring-driven fan, which forces it into a chamber divided by porous earthenware partitions into horizontal layers containing the spirits to be vaporized. The richness of the gas produced may be controlled by cutting off the air supply to one or more of the sections, suitable air

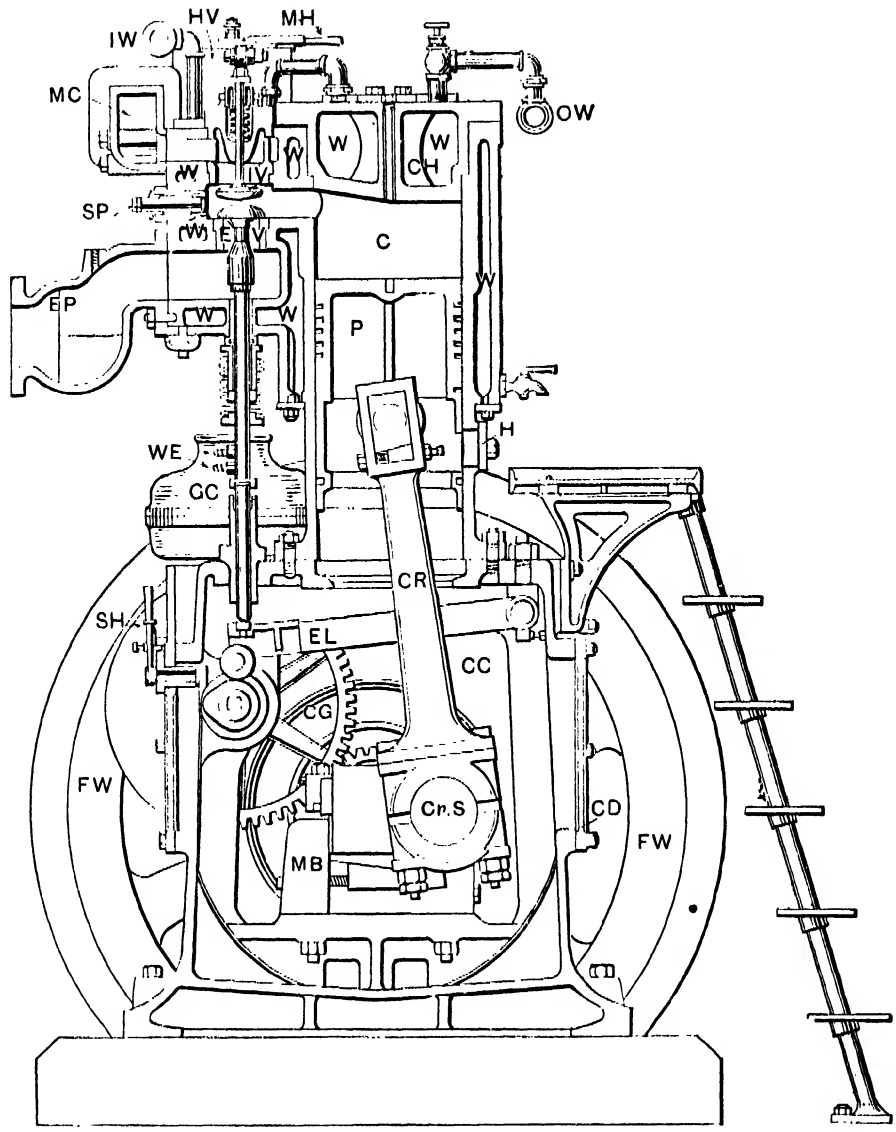


Fig. 306.—Sectional Side Elevation of Westinghouse Single-acting Gas Engine

C, Cylinder; CC, Crank case; CD, Crank-case doors; CG, Cam shaft gear wheel; CH, Cylinder head; CR, Connecting rod; CS, Cam shaft; CRS, Crank shaft; EL, Exhaust lever; EP, Exhaust pipe; EV, Exhaust valve; FW, Flywheel; GC, Governor case; H, Hole for adjusting piston-pin brasses; IV, Inlet valve; IW, Inlet water pipe; MB, Main bearing; MC, Mixture chamber; MH, Mixture regulating handle; MV, Mixing and governing valve; OW, Outlet water pipe; P, Piston; PP, Piston pin; SH, Starting handle; SP, Sparking plug; W W W W, Water jacketing; WE, Water connections for exhaust valve.

cocks being provided for the purpose. At the Antwerp exhibition of 1885 one of these carburettors was shown working in conjunction with a Benier engine, and the combined arrangement has been largely adopted for the lighting of houses and churches, and particularly of buildings that are not provided with a gas supply.

Lenoir Carburettor.—For many years, and particularly since the commencement of the rapid development of the gas engine, much attention has been given to the

design of suitable carburettors for oil-vapour engines. One of the most ingenious of these is the Lenoir carburettor, manufactured by Messrs. Rouart Bros., and applied to the Lenoir oil engine. It consists of a cylinder, which is rotated by the engine through suitable gearing at a speed of from five to six revolutions per minute. Vertical perforated diaphragms divide the cylinder into a number of compartments, and spiral recesses are formed in the inner wall of the chamber. As the cylinder rotates, the oil rises in the spiral recesses to the top, where it falls down in a shower, and thus saturates the air with vapour. The mixture of air and vapour is then sucked during the first stroke of each cycle into the working cylinder. Lenoir engines fitted with this

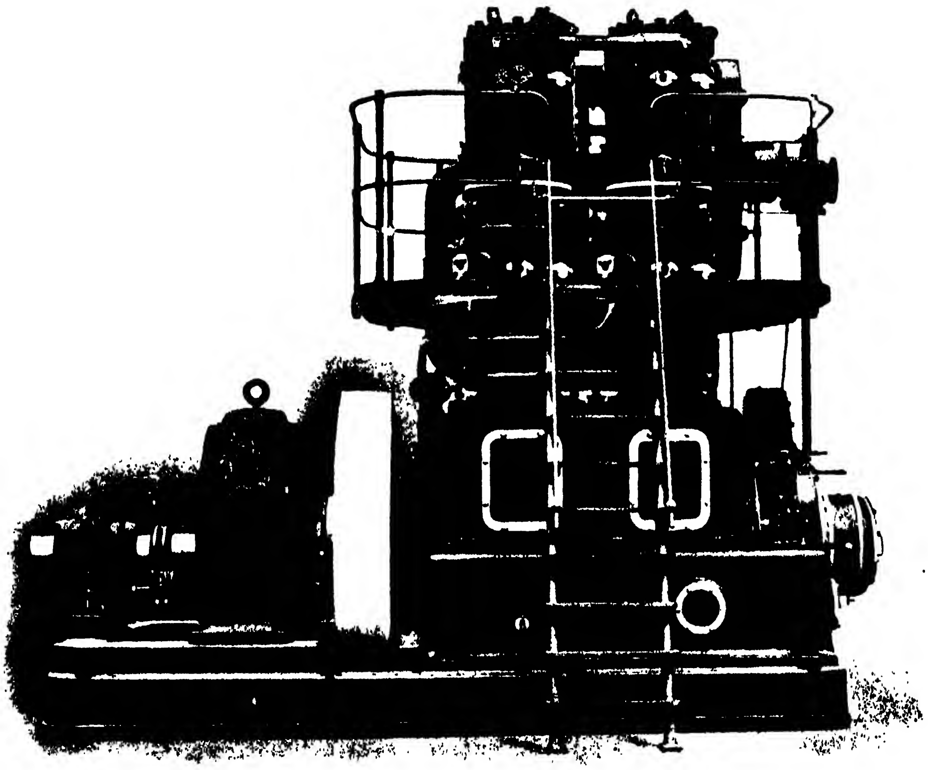


Fig. 367.—240-B.H.P. Vertical Tandem Four-cylinder Two-crank Gas Engine coupled to Westinghouse A.C. Generator

carburettor have been used with much success for the driving of agricultural machines and for motor launches.

Schrab Carburettor. Several novel features are embodied in this invention, which has given exceptionally economical results. The oil to be vaporized is circulated in the cylinder jackets instead of cooling water, and is thus heated to a temperature of about 80° C. It then passes through a chamber divided by partitions into several compartments, where it comes into intimate contact with the exhaust gases. These gases become recharged with hydrogen, carbon monoxide, and other highly combustible gases, and are again made suitable for combustion in the engine when the necessary oxygen is supplied. The inventor claims that the exhaust gases do not entrain more than one-sixteenth part of the amount of spirit vapour carried away by a stream of pure air, and in this way he accounts for the remarkably economical results that have been

obtained. A supply of $1\frac{3}{4}$ pint of gasolene per horse-power was found to be sufficient to run the engine for ten working hours.

Meyer Carburettor.—It is possible in this carburettor to completely volatilize heavy oils of a cruder and cheaper kind than ordinary gasolene. The oil to be vaporized is admitted, drop by drop, into a sheet-metal vessel about 3 in. in diameter and $1\frac{1}{2}$ in. high, which is heated by a gas-flame. The vapour thus formed under some pressure passes at a considerable speed through an air injector into a gasometer, and is prevented by a non-return valve from passing back again to the carburettor. By means of an automatic-valve arrangement the strength of the heater flame is reduced as soon as the gasometer is filled, and in this way the supply of vapour is automatically regulated to suit the demands of the engine.

Delamare Carburettor.—Mr. Delamare-Deboutteville has devised this very compact carburettor for use in conjunction with the Simplex engine, in which light oil vapours are burned. The gasolene contained in an elevated reservoir drips in a fine stream through a stop cock on to a spirally arranged horse-hair brush, where it comes into contact with a stream of heated water from the water jackets of the cylinder. Two purposes are served by the hot water. By raising the temperature of the spirit it increases the rapidity of the vaporization, and it also washes out any impurities that it may contain. The liquid gasolene and the water fall together to the bottom of the closed vessel, where the water is drawn off through a siphon and rejected. The combustible vapours pass to the engine through a valve which prevents all danger of the flame jumping back and igniting the explosive mixture in the reservoir. As a result of the preliminary washing of the gasolene the cylinder walls do not become foul, and are accordingly more easily kept in good condition, and the whole working of the engine is improved.

Lothammer Carburettor. Separation of the volatile spirit vapour from the air takes place as readily as the saturation of the air, and for this reason it is necessary to place the carburettor as near as possible to the engine cylinder in which it is to be consumed. In the Lothammer arrangement particular attention has been given to the production of a very intimate mixture of the air and vapour without, however, increasing the complication of the carburettor. The air enters the bottom of the carburettor, which is maintained at a constant temperature by means of a flame, and passes up through the gasolene in numerous fine jets, becoming in its passage uniformly charged with the combustible vapours. Good working results have been obtained from the Lothammer apparatus in the many applications it has received.

VAPOUR ENGINES

Durand Engine.—It is claimed for this engine that it is able to work equally well on gas or petroleum, and that it works regularly without attention, and is not costly although strongly constructed. To a certain extent these claims are justified by results; but the mechanism is somewhat complicated, and the design is not carried out on well-proven lines. It is a four-cycle engine with electric ignition, the spark being produced by the interruption of the current from a small magneto machine driven by the engine

itself, fig. 368. Governing is done by throttling the gas supply at the admission valve, and the air supply is sucked directly by the piston over a sieve heated by a special arrangement in which the exhaust gases circulate. From this initial heating of the air a certain economy of gas results. The carburettor is automatic and self-regulating. It consists of a hermetically-sealed cylindrical vessel filled with the oil supply. On the surface of the oil there floats a mass of cork, into the centre of which the air to be carburetted is led through a pipe in the cover. The cork acts as a sponge and soaks in the volatile spirits, which are thus brought into close contact with the air. The evaporation is always superficial, and the impurities remain in the bottom of the vessel. Petroleum having a

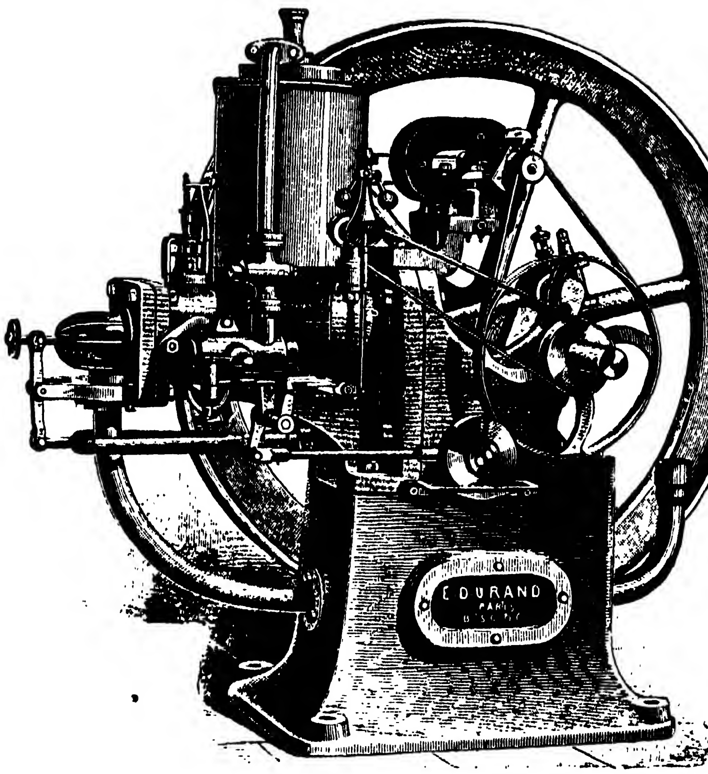


Fig. 368.—Durand Vapour Engine

specific gravity of about .7 is used, as it not only costs somewhat less than gasolene, but is also more readily procurable. As already stated, the one serious defect of the Durand engine consists in the number and the complication of the parts. In the case of gas engines, which are subjected to continual severe shocks, the fewer the working parts the better, as otherwise the wear becomes very considerable, and the difficulty of efficiently lubricating the working surfaces and the cylinder is increased.

Daimler Engine.—This motor is best known by reason of its extensive use in the motor cars of Panhard & Peugeot, which have earned for themselves the highest reputations for economy and general perfection. In the type of engine applied to motor cars, the cylinders, instead of being placed side by side, are arranged one behind the other in a position slightly inclined to the vertical. Compressed air enters the cylinders through a central valve as soon as the expansion is completed, and expels the products of combustion. The exhaust and admission valves, together with the

incandescent tube for the firing of the explosive mixture, are contained in a separate casing. Whenever the speed of the engine exceeds a predetermined limit, a governor on the shaft acts in such a way as to make the exhaust valve fail to open, and thus, by preventing the escape of the exhaust gases from the cylinder and the admission of the new explosive charge, causes the engine to miss explosions until the speed is sufficiently reduced. All the parts, including the flywheels, are entirely enclosed in an air-tight casing, which serves as a reservoir for the compressed air used in the expulsion

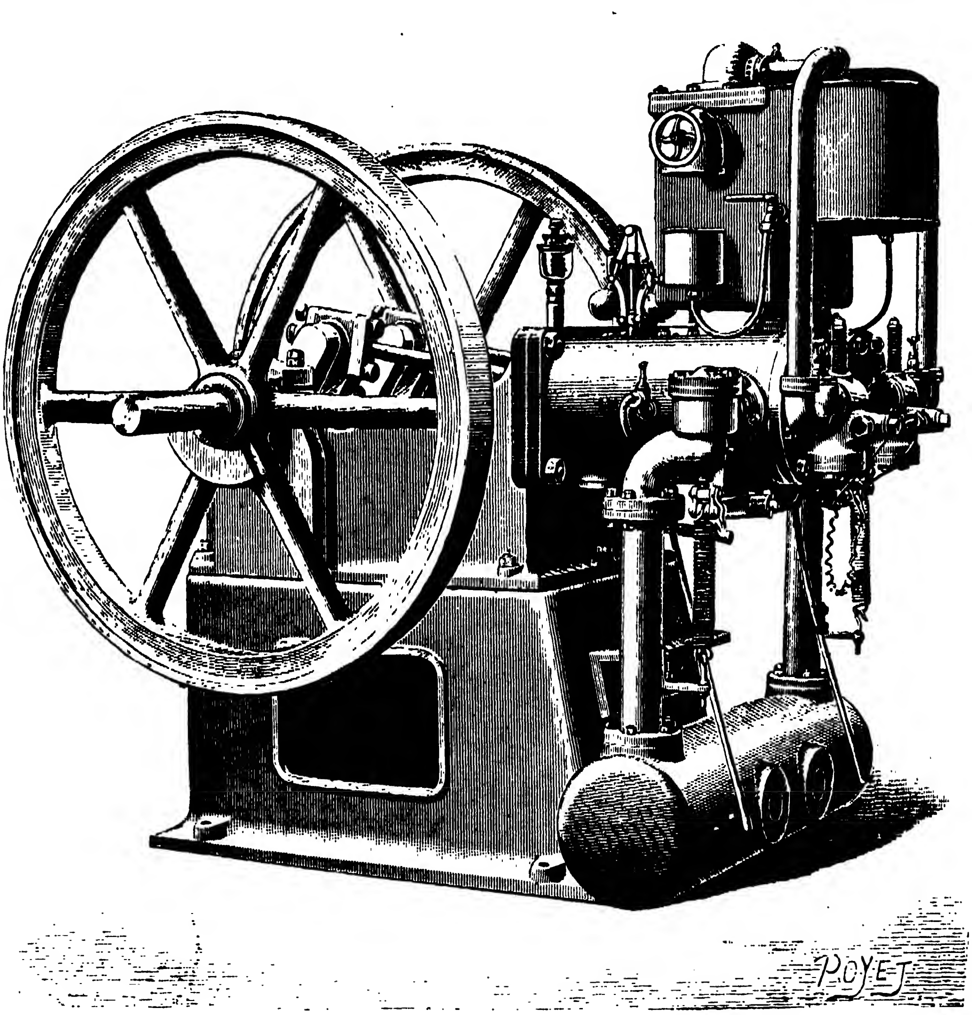


Fig. 369. Bruhot Engine for Agricultural Purposes

of the exhaust gases. The air is drawn into the casing through an automatic air-valve, which opens only from the outside inwards at each stroke of the pistons. The air to be carburetted is passed over the gasolene contained in a cylindrical vessel, and the supply of the mixture to the engine is very uniform. Water is circulated around the cylinders to cool them, and the water-cooling arrangements in the case of the motor-car type of engine consist of two concentric tubes running from end to end of the car. In the annular space between the two tubes the water to be cooled is circulated, while the cold air passes through the inner and around the outer tube.

Bruhot Engine. – Messrs. Bruhot, of Vierzon, have introduced a gas engine which can be run equally well on the light volatile oils, and is particularly suitable for

agricultural purposes. The engine, as arranged for town gas, differs from those already described in details alone. It works on a four-stroke cycle, and the firing of the mixture is done by means of a small battery, or by a magneto driven from the engine shaft. To make the engine suitable for running on oil vapour a carburettor and the necessary oil reservoirs are added. Air is sucked in by the motion of the pistons over the petroleum or other volatile mineral oils contained in the carburettor cylinder, and becomes charged with hydrocarbon vapours. In connection with the carburettor chamber is a tank containing a reserve supply of several pints of oil, and a special regulator keeps the level in the carburettor always constant, however variable the demands may be. The arrangement, which is both simple and strong, makes the engine particularly suitable for agricultural purposes.

CARBURETTED-AIR ENGINES FOR MOTOR CARS

Within the past few years the great development of the motor-car industry has opened a new field for vapour engines of the lightest and most compact kind, and to an ever-increasing extent these engines are being applied to such other purposes as the driving of boats' fire engines and portable pumps and drills.

Under the motor-car section carburetted-air engines have been described in considerable detail, and further reference to them here is therefore unnecessary.

OIL ENGINES

There is a great difference, especially as regards economy, between the volatile-oil or carburetted-air engines, already described, and those in which are burned the ordinary commercial petroleum and lamp oils. These oils have a specific gravity of about 0.8, and are less dangerous to use, as they do not give off inflammable vapours until a temperature of from 30° to 50° C. is reached. The price is also less than that of gasolene and similar spirits, and from the point of view of running costs there is a considerable advantage in using engines which burn ordinary illuminating oil wherever the conditions are favourable. In certain districts where town gas is costly or where suitable gas is not readily obtainable the use of these oil engines has very rapidly extended. The first example, from which the whole family of engines burning the heavier oils may be considered as derived, is the Brayton engine, introduced as early as 1872.

Brayton Ready Motor.—This engine belongs to the third class already mentioned, in which the gases are burned under pressure. It has two cylinders one for the compression of the mixture, the other being the working cylinder. In the course of the compressed air is formed a space, in which are packed absorbent materials, such as hemp and felt, and a special pump is provided to keep them constantly soaked with the oil. The carburation of the air then consists in blowing the oil carried by the porous mass of felt into foam by means of a jet of compressed air, and in then passing

the supply of pure air. In its passage through the felt the air becomes charged with a cloud of oil globules in a condition suitable for combustion in the cylinder of the engine. Heavy and relatively cheap oils may be used with equally economical results. They have the further advantage that the oily residues help to lubricate the cylinder. One volume of petroleum serves for the carburation of 24,000 volumes of air when working on the Brayton system. Both vertical and horizontal types of the engine are constructed, and the compression cylinder is generally arranged above the working cylinder. During the first third of the stroke the mixture of air and oil in an atomized

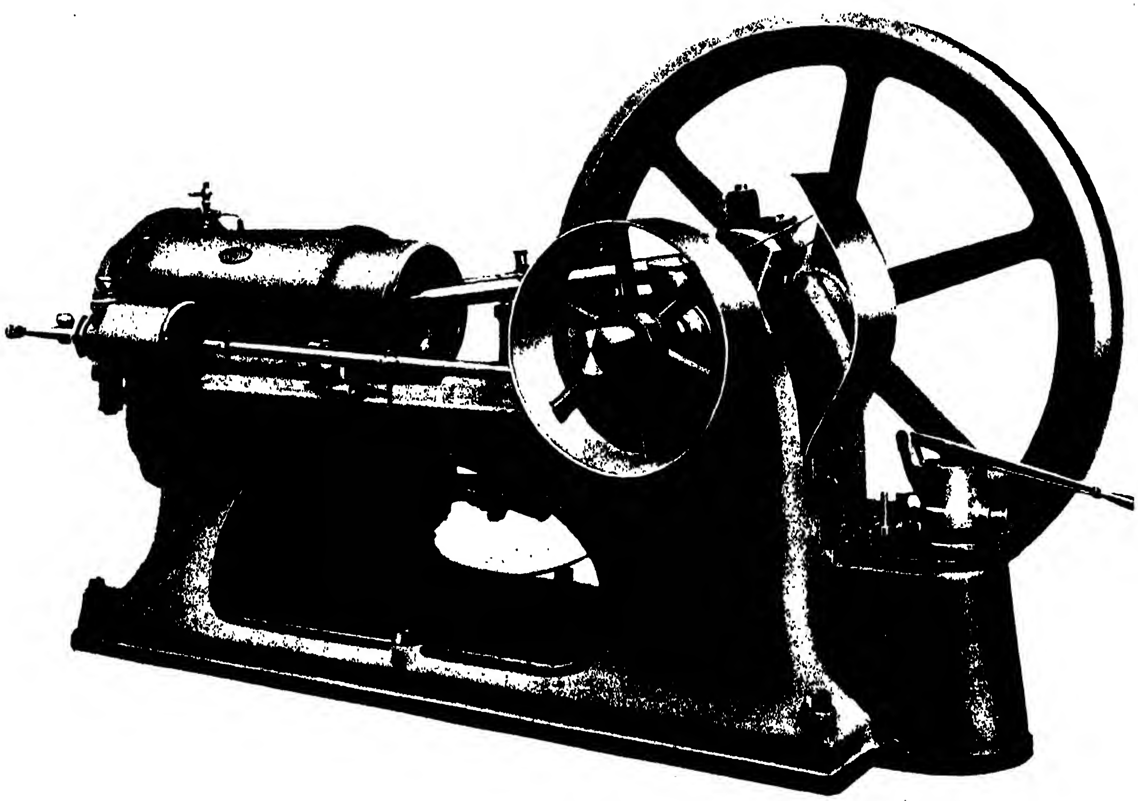


Fig. 370. Priestman Oil Engine

condition is admitted to the working cylinder, and after the firing of the charge the piston is driven to the end of its stroke by the expansion of the gases. Exhaust of the waste products takes place throughout the return stroke, and as the engine is double-acting a similar series of operations takes place on the other face of the piston. To dispense with the necessity, when starting, of turning the flywheel a reservoir of compressed air charged by the engine itself is provided.

Brayton engines are constructed for powers of from 1 to 10 h.p., and as the working costs are less than for carburetted-air engines they are particularly suitable for districts where town gas is not available or is too costly.

In 1890 an improved type of Brayton engine which gave still more economical results was introduced. It worked on the four-stroke cycle and was single-acting. As in the earlier engine, the oil was supplied to the cylinder in an atomized form, but

the arrangements were greatly improved. The rectilinear motion of the piston rod was transmitted through a beam and connecting rod, from which was also worked the piston of the compressor. Ignition of the mixture was effected by means of a platinum capsule kept at a red heat by the temperature arising from the repeated combustion in the cylinder. This latter feature distinguishes many of the engines burning illuminating oils, and the Brayton engine may be considered as the first example of a class which during the last few years has been brought to a state of great perfection.

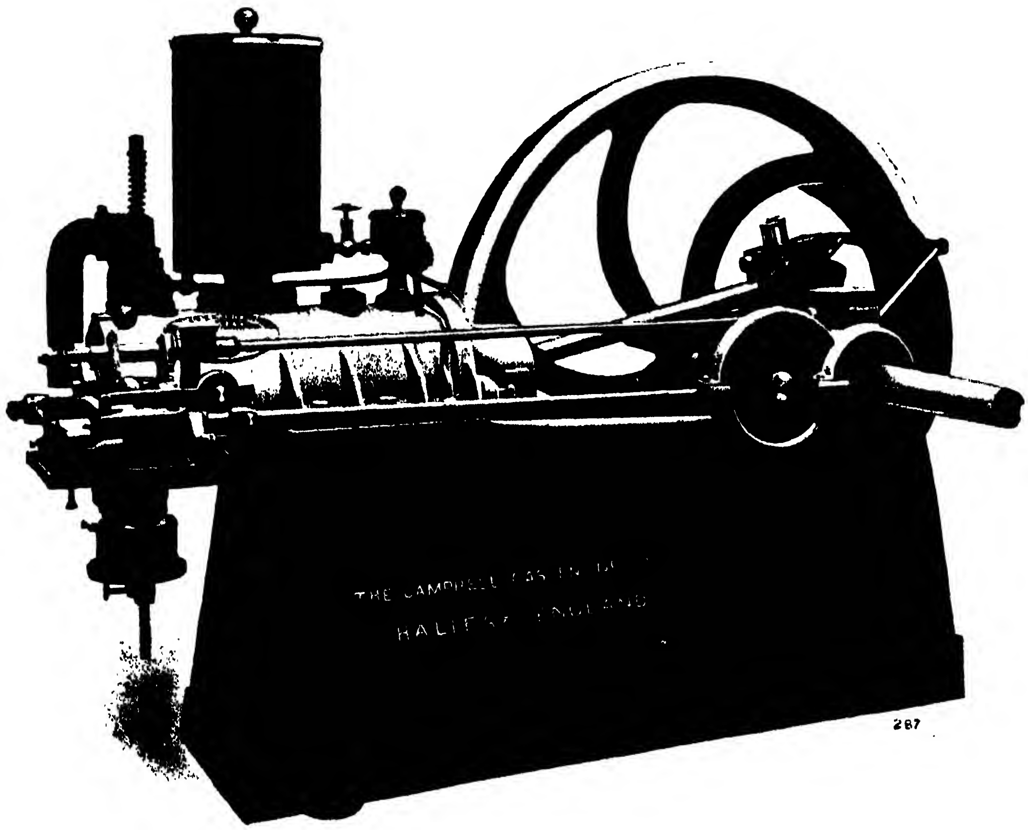


Fig. 371.—Campbell Oil Engine

Security Engine. The Security engine was patented in 1877 by Messrs. Belmont, Chabout, & Diederichs, and is built at Bourgoin in France. It works on the four-stroke cycle, and ignition is effected by means of a tube heated to redness by the combustion of a mixture of compressed air and vapour, which is circulated in a spiral tube heated by the waste heat from the cylinder. Communication between the interior of the heated tube and the combustion chamber is controlled by means of a special valve so that the moment of the explosion may be very exactly regulated. Another spiral tube placed in the course of the hot exhaust gases serves for the vaporization of the oil, and the vapour thus formed has sufficient pressure to entrain the necessary supply of air as it passes through an injector into the cylinder. To start the engine from the cold condition the air is initially carburetted with a small quantity of gasolene, and this process is continued until the spiral becomes sufficiently hot, when the action becomes entirely automatic. Later engines of the same general type have given much

better results, but the use of two separate arrangements for vaporizing the oil introduces much complication, and the cost is excessive in comparison with the economy obtained.

Priestman Engine.—This interesting engine dates from 1886, when a patent was granted to Dent & Priestman. In general principle it resembles the Otto engine, but to permit of the use of heavy-oil vapours a special arrangement of an ingenious nature has been provided. Compressed air is supplied by a single-acting pump at a pressure suitable for the particular size and power of the engine, and is stored in a reservoir which is placed at the front of the engine and provided with a non-return

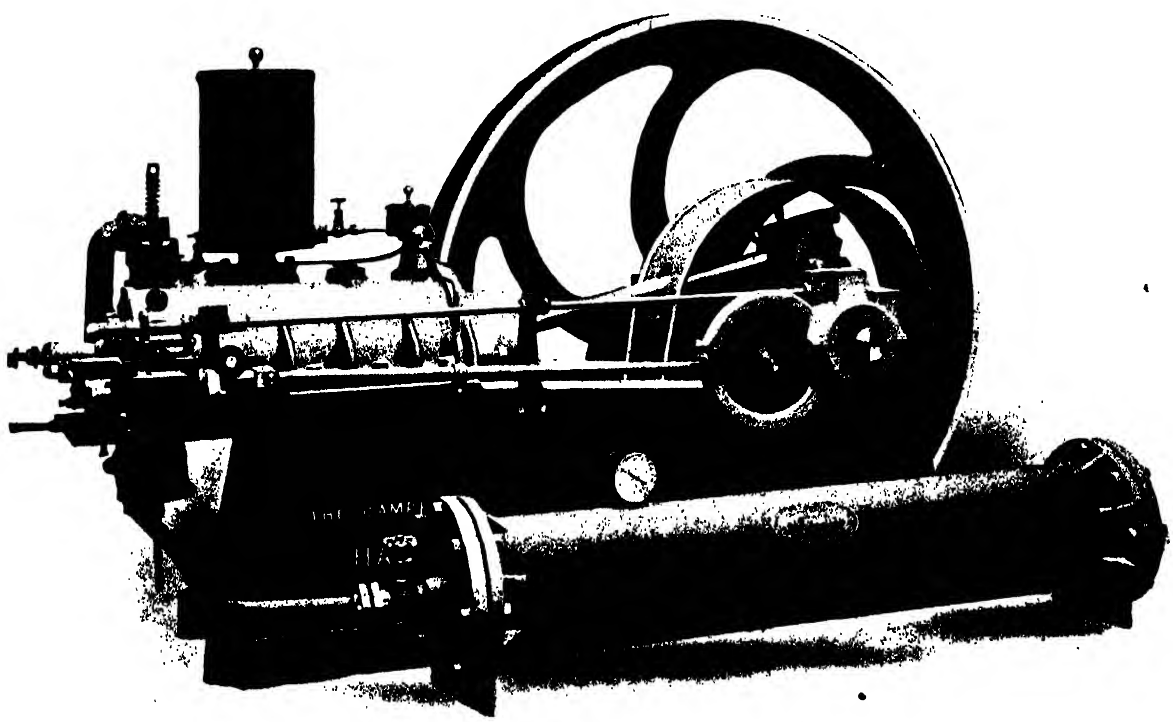


Fig. 372.—Campbell Oil Engine, Electric Lighting Type, fitted with Starting Apparatus

regulating valve. The pump is driven by an eccentric keyed to a half-speed shaft, which, as the name implies, is so geared as to run at half the speed of the crank shaft. As the compressed air enters the reservoir in a jet, it sprays the oil contained in the chamber and carries it over in a state of fine division into a vaporizer heated by the exhaust gases. A further supply of air is added to bring the mixture to an explosive condition before its admission through an automatic valve into the explosion chamber. After the compression and the working strokes are completed, the exhaust of the waste gases takes place through a valve controlled from the same shaft which operates the air-compressing pump. In this way the number of the working parts is reduced to a minimum, and the inevitable losses due to soiling that result in other systems from the transfer of the oil vapours at a high temperature are avoided. Horizontal engines of from 1 to 50 h.p., fig. 370, are in frequent use, and engines of the vertical marine type are built in sizes ranging from 3 to 100 h.p. To start the Priestman engine a special lamp and automatic cock are provided, and the operation does not require

PRIESTMAN OIL ENGINE

INDEX TO THE PRINCIPAL PARTS

1. Foundation.
2. Engine Bed Plate.
3. Foundation Bolts.
4. Air Trunk.
5. Air Pump.
6. Belt Pulley.
7. Oil-tank Air Inlet.
8. Air-pump Piston.
9. Air-inlet Valve.
10. Air-discharge Valve.
11. Tail Rod for Operating Valve.
12. Valve-lever Coupling.
13. Eccentric Rod.
14. Driving Arm on Eccentric Rod.
15. Eccentric.
16. Crank-shaft Bearing.
17. Eccentric-shaft Bearing.
18. Air-pressure Gauge.
19. Cylinder.
20. Admission Valve.
21. Exhaust Valve.
22. Piston.
23. Connecting Rod.
24. Crank.
25. Eccentric Spur Gear.
26. Oil Chamber.
27. Sheet-metal Guard.
28. Governor.
29. Governor Belt.
30. Crank Shaft.
31. Eccentric Shaft.
32. Exhaust Pipe.
33. Vaporizer.
34. Vaporizer Lamp.
35. Oil-sprayer.
36. Oil-pipe Connection to Spray.
37. Oil Pipe to Lamp.
38. Oil Tank.
39. Hand Pump.
40. Water Jacket.
41. Jacket-water Admission Pipe.
42. Jacket-water Outlet Pipe.
43. Electric-ignition Accumulators.
44. Electric Connections to Ignition Plug.
45. Ignition Gear.
46. Ignition Plug.
47. Contacts (not numbered).
48. Flywheel.

(*Model prepared from drawings kindly supplied by* Messrs PRIESTMAN & Co., LONDON.)

more than a few minutes. When once started, the ignition is effected either electrically or by means of an incandescent tube, as may be preferred by the user.

Campbell Engine.—As few working parts as possible are used in the Campbell engine, and the design is of a very substantial kind. Three valves only are involved, and one of these is controlled by a centrifugal governor which determines the admission of the mixture and the power developed from moment to moment. The vaporizer is

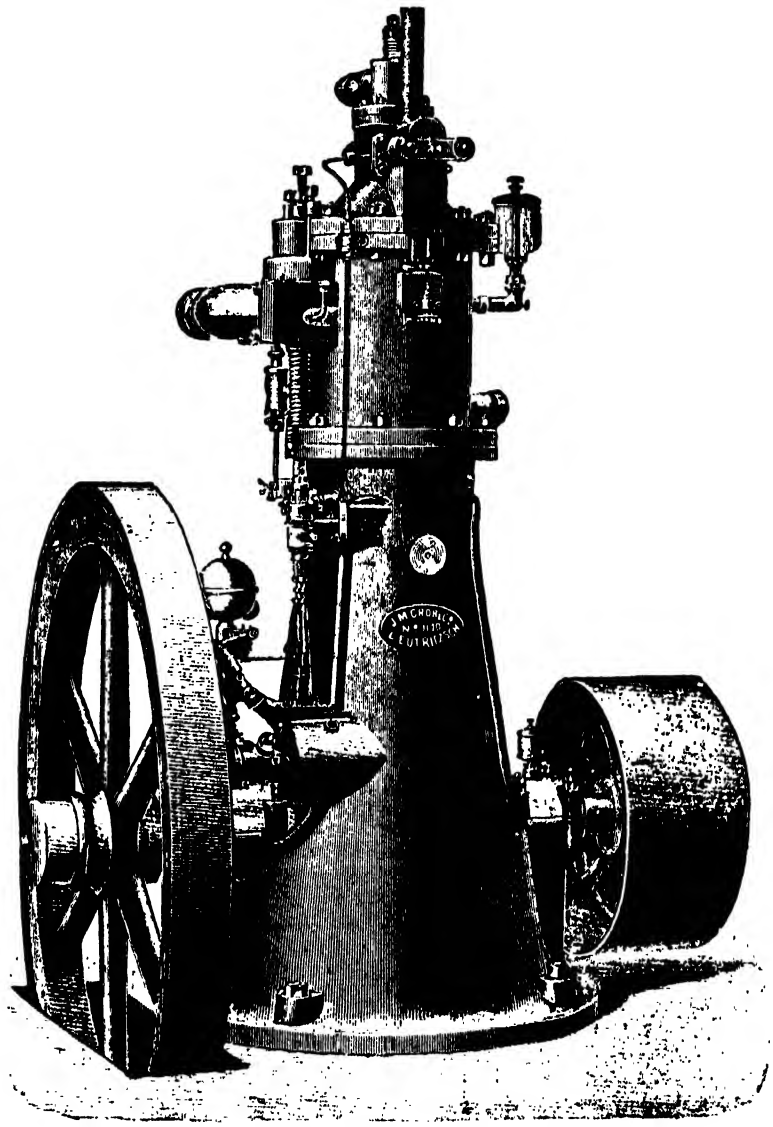


Fig. 373.—Vertical Inverted Grob Oil Engine

heated by means of an oil lamp, and the starting of the engine is not difficult; but in the engines, figs. 371, 372, a starting arrangement is provided, the reservoir being shown at the side of the engine in fig. 372. The cheapest brands of petroleum may be burned without trouble, and the engine is controlled by a special type of balance governor positively driven from the shaft.

Grob Engine.—As illustrated in figs. 373 and 374, this engine is arranged vertically with the cylinder at the top and the crank shaft with its flywheel and driving pulley at the bottom. It works on the Otto four-stroke cycle, and is designed to run

on ordinary commercial petroleum. The action is as follows: A pump driven by the engine injects the oil to be vaporized into an atomizer, which breaks up the inflammable liquid into an extremely fine cloud of globules. The mixture of air and oil then passes into a tube exposed externally to the action of a flame, where the charge

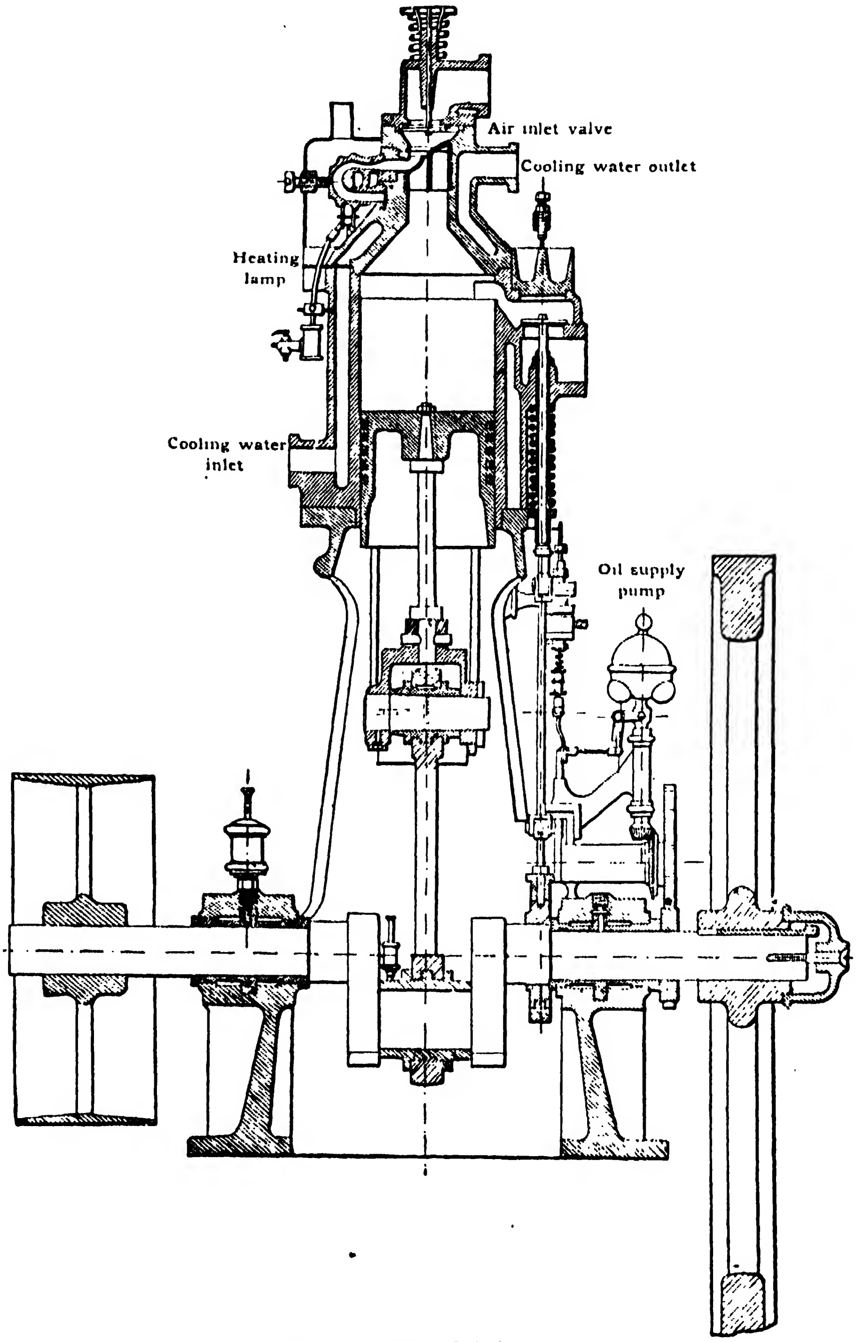


Fig. 374.—Section of Grob Engine

is gasified before its entrance into the cylinder. By these means the oil is vaporized without the use of complicated gear, and the oil is admitted in the state of vapour into the cylinder, where it is ignited at the proper instant by contact with an incandescent tube. Initial compression of the charge makes it possible to reduce the diameter of the cylinder, and with it the weight of the engine for a given output, as the expansion

is to a corresponding degree more energetic. Regulation of the speed takes place on the "hit and miss" principle, the ignition of the charge being suppressed whenever the speed exceeds certain predetermined limits. Under the ordinary working conditions the walls of the cylinder are allowed to remain at a temperature sufficient to ensure the combustion of the mixture.

Efficient water-jacketing arrangements are essential in all heat engines of the internal-explosion type, to prevent the cylinder walls from reaching a temperature that

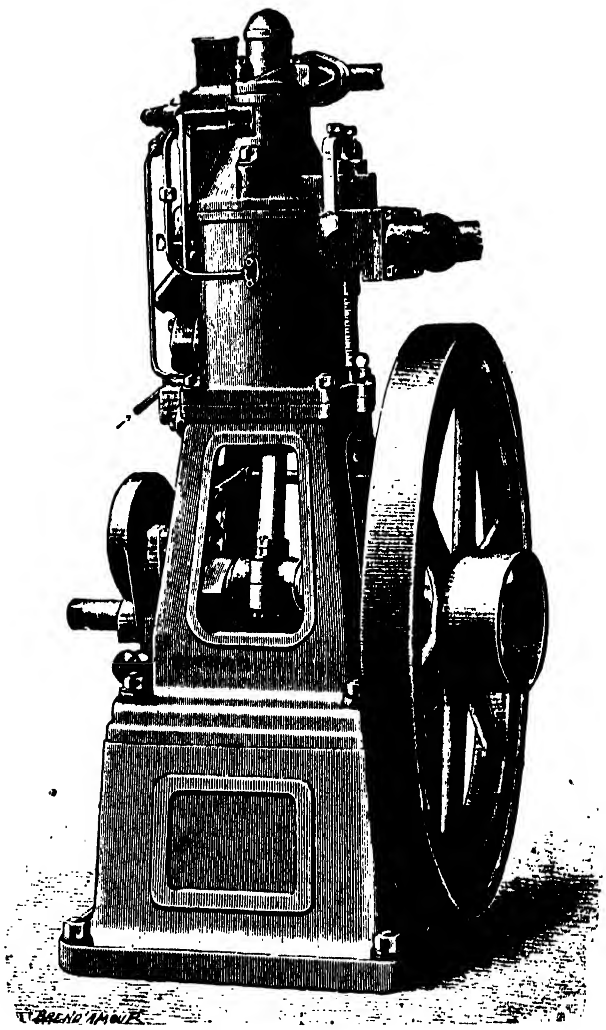


Fig. 375.—Capitaine Engine

would interfere with the lubrication of the working parts. If no cooling arrangements were provided, the cylinder walls would, after a very few explosions, become red hot. When a continuous supply of cold water is not available, it is necessary to recool the water after its passage through the jackets, so that the same quantity of water may be repeatedly used. In the Grob engine the cooler adopted consists of a cylindrical sheet-metal reservoir, having a capacity which is designed to suit the power of the engine. For each horse-power a water capacity of about $2\frac{1}{2}$ gal. is allowed. The heated water from the cylinder jacket passes into the cooler at a temperature of about 70° C., and trickles over wooden screens occupying half the height of the cylinder. In its passage

over the gratings the water comes in contact with a strong blast, supplied by a fan at the side of the chamber. In this way the temperature of the water may be reduced by the vaporization that takes place to from 20° to 25° C., at which temperature it is sufficiently cool for reuse in the water jacket.

Both the Grob and the Merlin engines are based on the system of the Capitaine engine, which will be next described, but they do not work with the same regularity, and are not so well designed. In the Grob engine in particular the principle of the vaporizer is defective, as the oil, through being gasified at a high temperature, tends to decompose and settle in an objectionable form on the surfaces of the warm parts. This

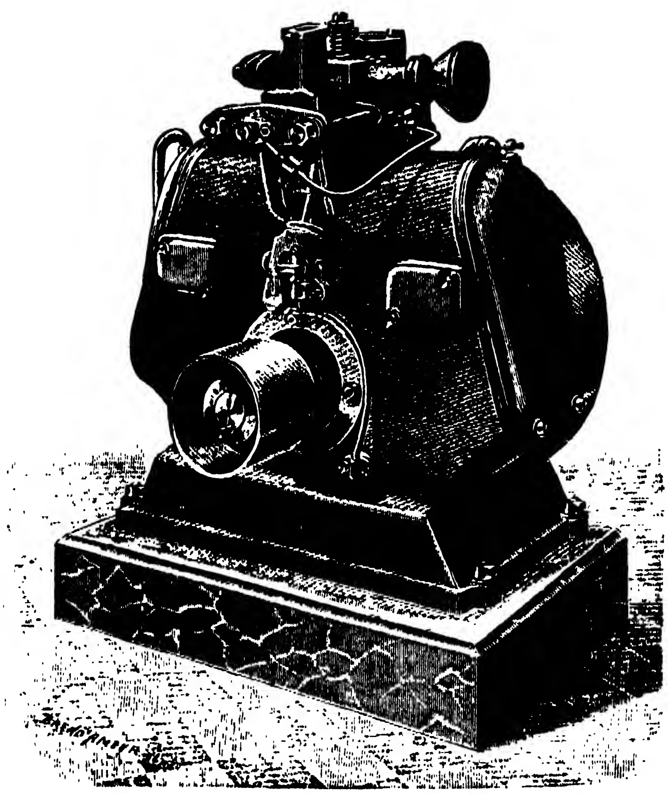


Fig. 376. Horizontal Balanced Cylinder Capitaine Engine

defect is one which is common to many engines that in other respects are well designed.

Capitaine Engine.—Before the commencement of his experiments on oil engines, Emile Capitaine had already gained considerable experience in the design of gas engines, to the development of which his work in no small degree contributed. His first oil-engine patent dates from 1879, and from that time until 1886, when a further patent was granted, he carried out a continuous series of laborious and costly experiments with a view to devising an engine which would run satisfactorily on ordinary lighting petroleum having a density of about 0.88.

Good results were obtained from the early engine, which worked without either flame or heating tube; but it was found necessary to give each time a full charge, or at the least 75 per cent. Otherwise, if the charge were too small or omitted, the vaporizer chamber, which was maintained at the necessary temperature by the repeated explosions, became

chilled to too great an extent. From this it will be evident that the engine could only work under certain conditions. Numerous experiments were also made with a view to arriving at a type of engine which would work equally efficiently at full and low loads, the consumption of oil being proportional to the power developed. Two new patents were obtained for a system of regulating the temperature, but the gear was of too complicated a nature, and finally, after much experimenting, Capitaine adopted the lamp heating system, which has given very good results. In this later type of engine the vaporizer remained always in communication with the interior of the cylinder, but its

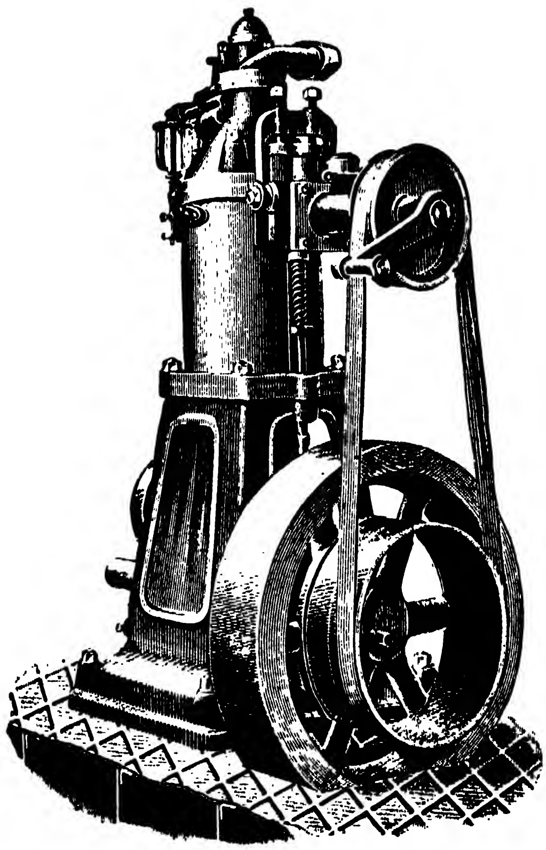


Fig. 37A.—Capitaine Launch Oil Engine

form was such that even when heated to redness premature explosion of the mixture did not take place, and the formation of carbonaceous deposits on the inner surfaces was entirely avoided.

In the Capitaine engine of 1892-1893, although a vaporizer lamp is provided, it may be dispensed with, as the engine can also work on the pneumatic system employed in the 1886 type, with, as before, the conditions that the charge must not be less than 75 per cent of the full amount, and that the number of explosions must not be reduced. Considering the uniformly good diagrams that are obtainable from the Capitaine engine without a heating lamp, when the temperature of the vaporizer varies within considerable limits, all that is necessary for successful working is to enclose the vaporizer and to allow it to retain as much as possible of the heat of each explosion. Above all, it is essential to protect it during the suction period from the contact of cold air or of gas at

a lower temperature. By observing these conditions Capitaine has succeeded in devising a type of engine which gives excellent results and does not involve the use of a heating lamp. By carefully coating all the surfaces with refractory non-conducting materials, he has also succeeded in placing the vaporizer within the combustion chamber itself. In this arrangement, which forms the subject of a separate patent, a quantity of hot and expanded gas is allowed to pass into the vaporizer by means of a small valve, which opens at the end of the expansion stroke, and closes immediately thereafter, when the large

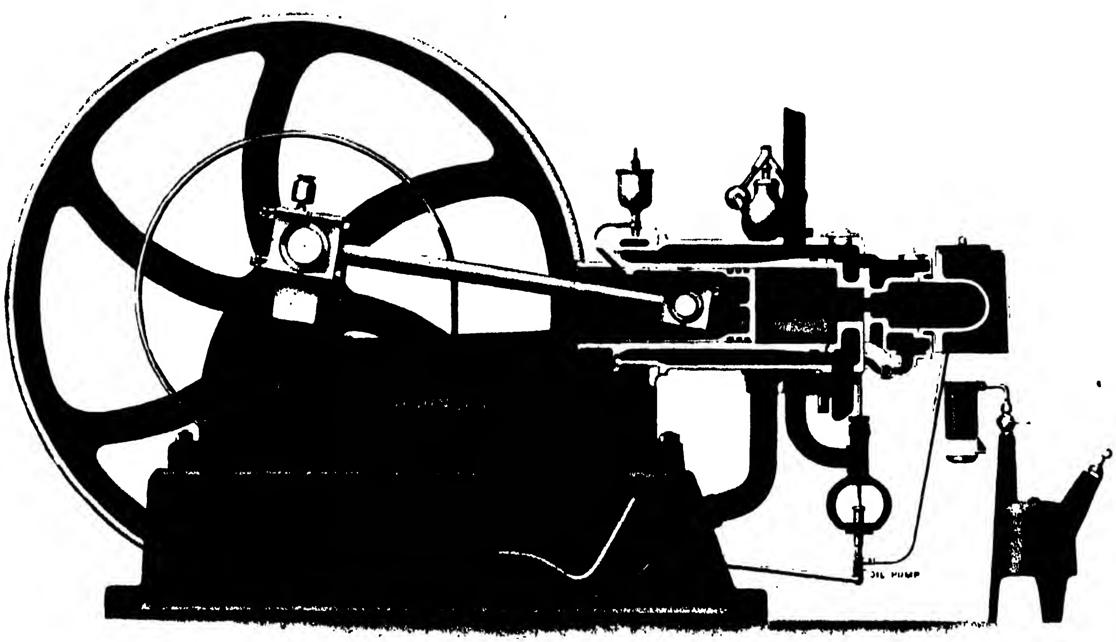


Fig. 378.—Hornsby Oil Engine. Section through Cylinder

exhaust valve is opened. To start the engine from the cold condition the vaporizer must first be heated by means of a hand lamp for two or three minutes.

The characteristic features of the engine may be summarized as follows:—

1. It dispenses with a heating lamp or other similar gear.
2. Only two or three minutes are required for the starting of the engine, owing to certain features in the design of the vaporizer: (*a*) the limited admission of air; (*b*) its inclusion in the combustion chamber; (*c*) the use of non-conducting coverings; and (*d*) the use of the very hot gases for heating it.
3. The vaporizer is not cooled during the suction stroke, or when explosions are missed for the purpose of economically regulating the speed.

Merlin Engine.—To some extent this vertical type bears some resemblance to the one just described, but the arrangement and certain of the details are entirely different. In the base is formed a reservoir in which is stored the supply of oil for the engine. An air pump communicating with the reservoir forces the oil up to a

second pump, which then drives it drop by drop through an atomizer into the vaporizer. At each stroke of the piston the valve of the atomizer opens and closes automatically, and the gasification takes place by atomizing and vaporizing the oil. A special form of heating lamp, giving an intense flame, is used for maintaining the temperature of the vaporizer. The engine works on the four-stroke cycle, and the firing of the mixture takes place in contact with the walls of the vaporizer, which have a temperature sufficiently great to prevent all danger of miss fires. A governor acts upon the oil-supply pump in such a way as to make the consumption vary with the power developed, and at the same time it further controls the speed by acting on the exhaust valve and thus

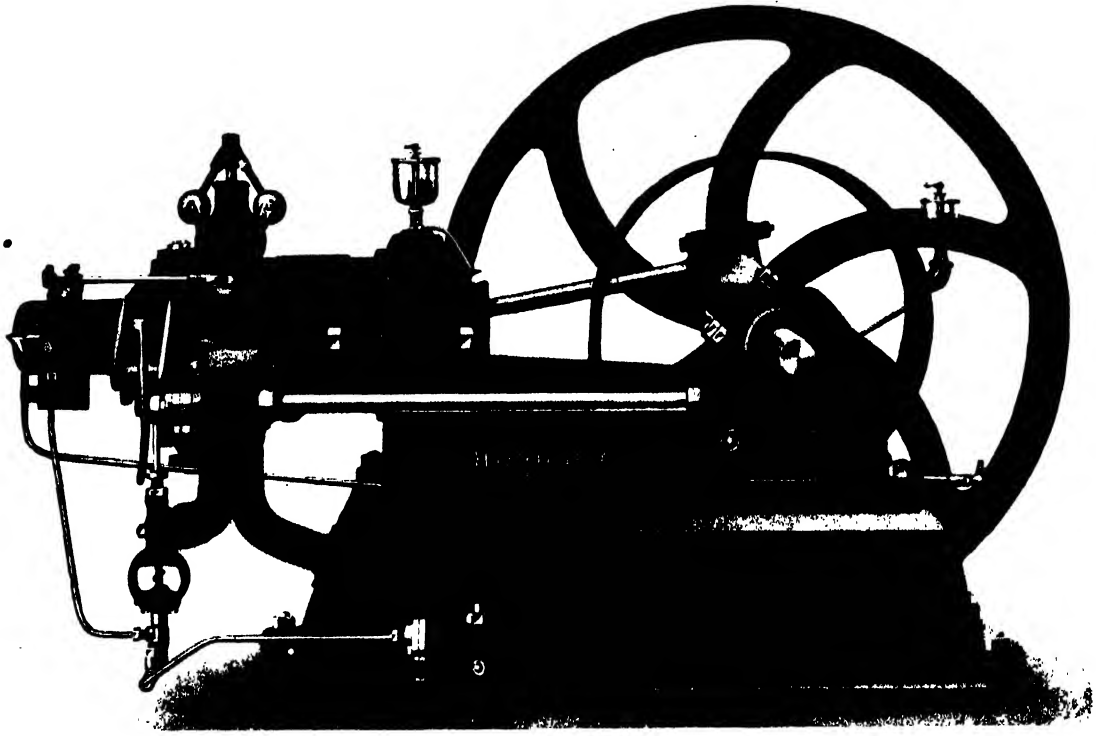


Fig. 379.—External View of Hornsby Oil Engine

preventing compression. The working speed of the engine is very great. Although this engine was awarded the first prize at the special exhibition for oil engines held in 1894 at Meaux, it is now in very many respects inferior to other types of later design.

Hornsby Engine. Any of the common commercial oils, from the ordinary lighting petroleum to the heavier oils having a flash point of 100° open test C., may be used without a carburettor in this engine. The base of the engine serves as a reservoir for the oil supply, and the arrangement throughout has been made of the simplest possible description to ensure freedom from breakdown. Fig. 378 is a section through the cylinder and valves, which will serve to illustrate the action, while fig. 379 shows the external appearance of the engine. A special portable oil lamp at the end of the cylinder serves to heat the vaporizer chamber when starting the engine, and about ten minutes are required with the oil flame to heat the vaporizer to a tempera-

ture sufficient to ensure the ignition of the explosive mixture. The chamber is connected to the cylinder by a small pipe, through which the air in the cylinder, compressed during the return stroke of the piston, is driven. In this way the chamber becomes filled with compressed air. Towards the end of the same stroke the exact quantity of oil required to form an explosive mixture is injected into the chamber by means of a pump which is driven from a cam on the half-speed shaft of the engine. To regulate the supply of oil, the stroke of the pump piston may be varied by adjusting the position of a stop piece which limits the travel. After the cam has completed the discharge stroke of the piston, the return stroke is made under the action of a spiral spring until

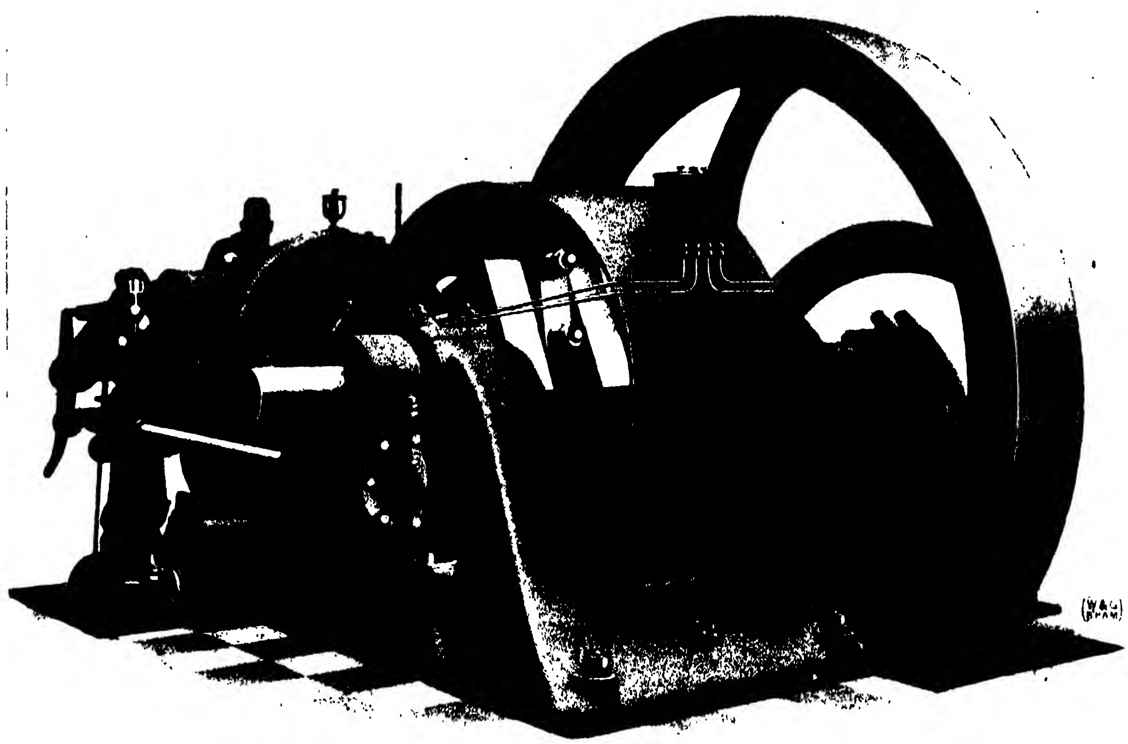


Fig. 380.- Hornsby Oil Engine with extra Flywheel and outer bearing for Electric Lighting purposes

the stop comes into action. The delivery valve of the pump is under the control of the engine governor. Rapid and complete vaporization of the oil takes place as soon as it is injected into the compressed air, and the mixture immediately explodes in contact with the heated walls of the chamber. To start the engine after the vaporizer has been heated with the lamp for a short time, it is necessary to turn the flywheel by hand until the first explosion takes place, after which the lamp may be extinguished, as the repeated explosions are sufficient to maintain the temperature of the vaporizer. In figs. 378 and 379 the oil pump, which is of the plunger type, is shown attached near the cylinder end of the base, and the suction and discharge oil pipes are also shown, the former communicating with the reservoir in the base, and the latter with the vaporizer. When the speed exceeds the fixed limit the governor closes the oil-admission valve from the vaporizer and returns the oil to the reservoir. As in all other four-stroke cycle engines in which the power is controlled by suppressing the ignition,

it is necessary to provide sufficiently heavy flywheels to ensure uniform running. Water jackets are provided to cool the walls of the cylinder. Scotch shale oils of a density of 0.85 may be burned in the engine, the consumption being less than 1 pt. per horse-power hour. Carbonaceous deposits do not form so readily as in other types of engines, and less trouble is experienced in this respect.

An illustration of a Hornsby oil engine of a specially solid construction is given in fig. 380. It is intended for electric lighting purposes, and has an extra heavy flywheel supported by an additional outer bearing.

Ragot Engine.—As in the examples already given, this engine, figs. 381 and 382, is designed to work on heavy oils, and particularly shale oils, which do not vaporize at

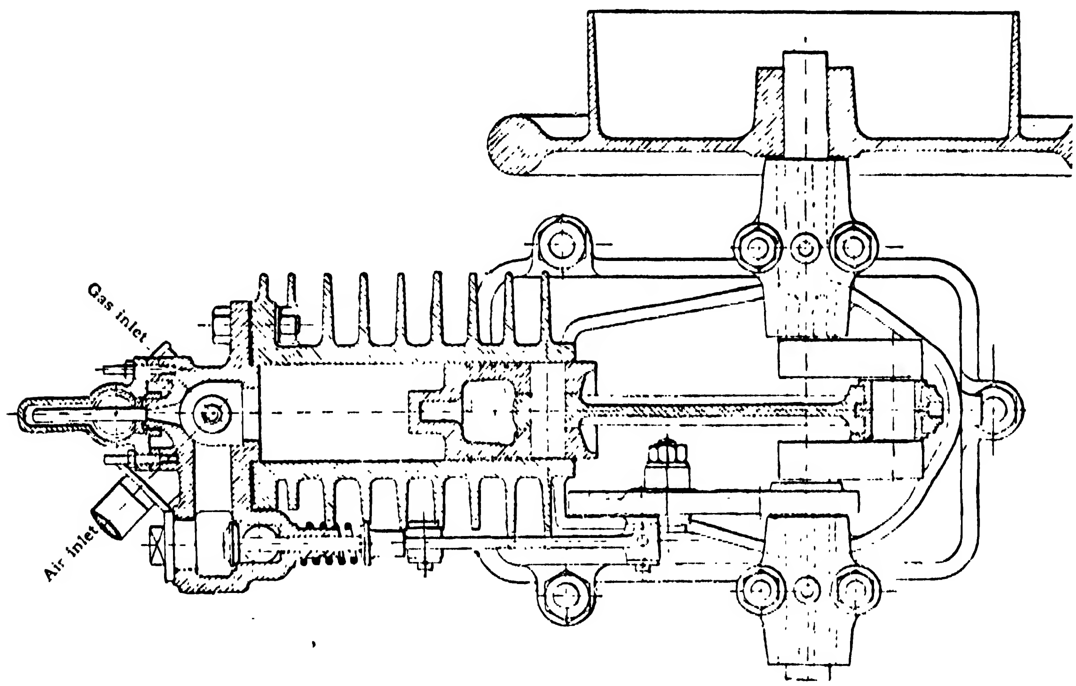


Fig. 381.—Sectional Plan of Ragot Oil Engine

a temperature below 45° C. It has the further advantage of being considerably less in cost than other engines in which such oils as naphtha, benzene, and gasolene are burned. To suit various conditions the engine is built in a number of different forms and sizes, and in its application to electric lighting it has been particularly successful, owing largely to the low price of the fuel and the correspondingly low price of the power, and also to the regularity of the motion. Later modifications of the parts have been successfully made, with a view to making the engine so simple that a person not specially skilled in the work may not only keep the engine in good condition, but also, when required, erect, or dismantle it for overhauling. The Ragot carburettor shown in the illustration, fig. 383, is particularly well designed, and deserves special notice. It is so arranged that the heavier portions of the petroleum or shale oil are first absorbed, so that the cleaning that is required is of an inconsiderable amount. As shown in the sectional elevation, fig. 383, the carburettor portion consists of a cast-brass tube, smooth internally and provided on the outside with a spiral web, which forms,

when enclosed in a casing, a continuous spiral passage heated by the strong flame of an oil lamp. The oil enters through the funnel mouth and descends the long spiral passage, which is more intensely heated at the bottom near the lamp than at the top, where the lighter vapours are first driven off. As the oil reaches the hotter portion the heavier portions that otherwise would have remained as residue are in turn volatilized, so that the vaporizer does not tend to become choked. The air to be carburetted enters at the bottom of the spiral and passes through it in the direction opposite to that of the oil. Before, however, mixing with the vapour the air is passed through

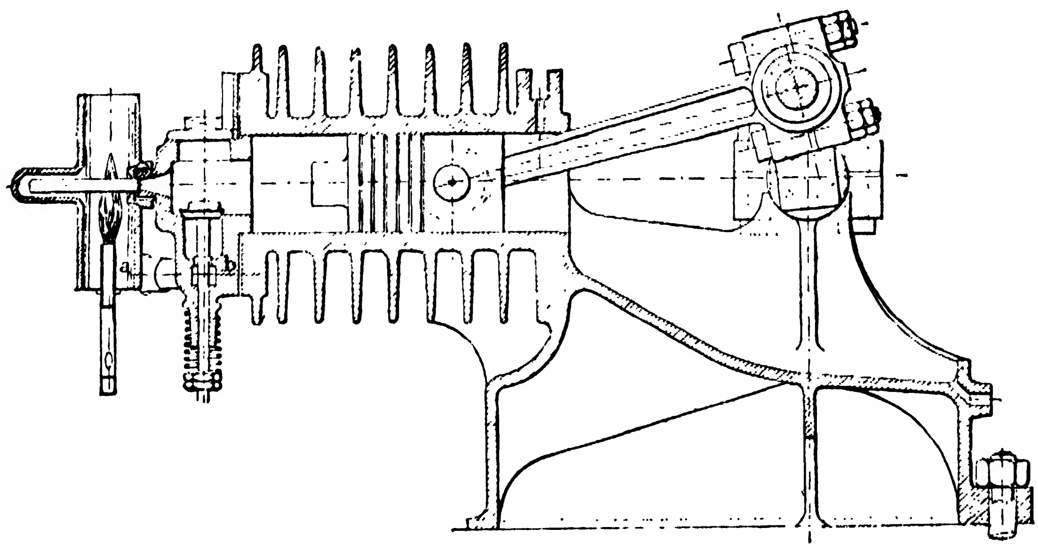


Fig. 382. Sectional Elevation of Ragot Oil Engine

a jacket surrounding the spiral, where it becomes heated to a temperature more nearly equal to that of the oil.

Root Engine. The Root engine, which works on the usual four-stroke cycle, is characterized by a novel arrangement of the ignition which takes place in two stages. A chamber at the side of the cylinder communicates with the rear end of the latter through a port which becomes closed by the piston when it reaches the end of its stroke. During the compression a portion of the explosive charge is driven into the side chamber, and then by the covering of the port it is cut off from the remainder of the charge, which becomes compressed in the usual way by the further movement of the piston. When the main charge is exploded the piston is driven forward, and as soon as the port becomes uncovered the remainder of the charge enclosed in the side chamber passes into the cylinder and gives a second explosion behind the piston. It is doubtful if the slight advantage that may be gained warrants the extra complication involved. For the ignition an incandescent tube is used, and the waste exhaust gases are utilized for heating the vaporizer and also for heating a spiral passage through which the air supply is passed. A very simple type of oil pump is used in connection with the vaporizer. It consists merely of a piston which moves to and fro in a cylinder, and which has on its face a channel for the passage of the oil. As the piston moves in one direction it draws in the oil from the reservoir, and on the return stroke it forces it towards the chamber where it comes into contact with the air supply. The admission

valve beyond which the air and vapour mix together is automatic, being only held upon its seating by a spiral spring; while the exhaust valve is operated positively from the same shaft which drives the vaporizer oil pump.

Knight Engine. With a view to completely expelling the exhaust gases from the cylinder, Mr. Knight has adopted the Griffin six-cycle double-acting system which has

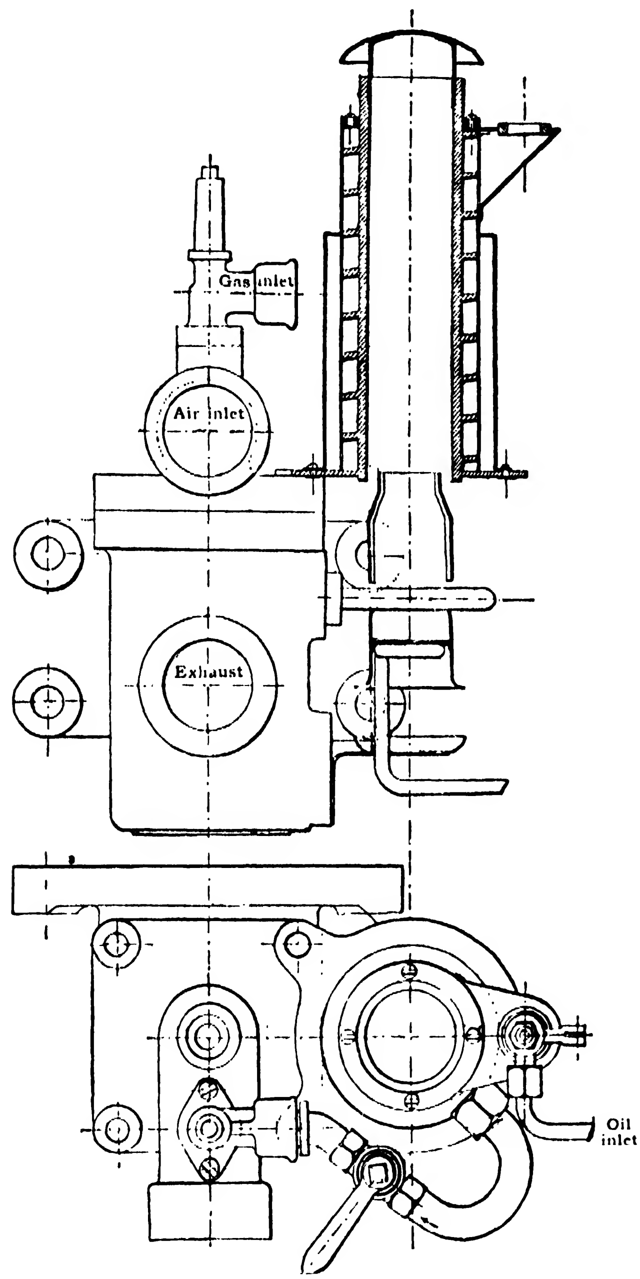


Fig. 383.—Carburettor of Ragot Oil Engine

already been described. This system has at least the great advantage of giving a very uniform rotation of the driving pulley. The vaporizer, which is of gun-metal with cast webs, is placed behind the cylinder and is only separated from it by a thickness of sheet metal in order to derive as much value from the heat of the cylinder as possible. Two pumps are provided for supplying the oil and the compressed air respectively to the

vaporizer, and the mixture is fired by means of a platinum wire heated to incandescence by means of a jet of flame formed by a central air blast. The ignition wire is contained in an opening in the ignition slide, which moves so as to bring the incandescent wire into contact with the mixture compressed behind the piston at the correct moment for the explosion. Between the cylinder and the vaporizer, in the sheet-metal separating plate, is placed the admission valve, which is constructed of an incombustible asbestos compound. As the other parts of the engine have no features of outstanding interest they will not be dealt with here.

Crossley Engine. This engine is the same as that already described in the section devoted to gas engines, with the addition of a special type of vaporizer, which

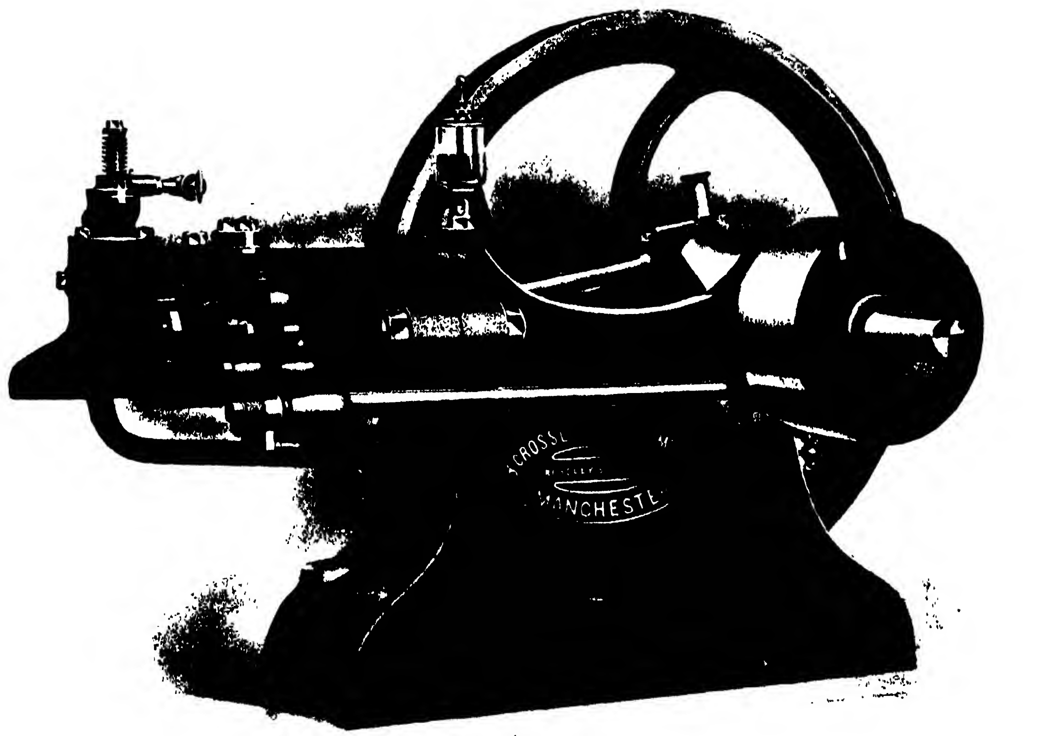


Fig. 384.—Crossley Oil Engine

enables a combustible mixture of air and oil vapour to be used instead of coal gas. The vaporizer consists of a chamber divided by vertical walls into four canals, through which the flame from a lamp passes upwards to the exit chimney at the top, while a single-acting pump driven by a lever forces a stream of air through a hot spiral passage encircling the lamp chimney. After its passage through the spiral the heated air comes into contact with the oil, a portion of which is entrained and carried over. Instead of the wick customarily used in the heating lamps of other engines the system of feeding the oil by means of a small pump has been adopted, and after the engine is well started the lamp is not required, as the heat of the explosions maintains the temperature of the vaporizer. Various modifications and improvements of this engine have been made since its first appearance, the principal being the reduction of the time required for the preliminary heating of the vaporizer when starting the engine, and the simplification

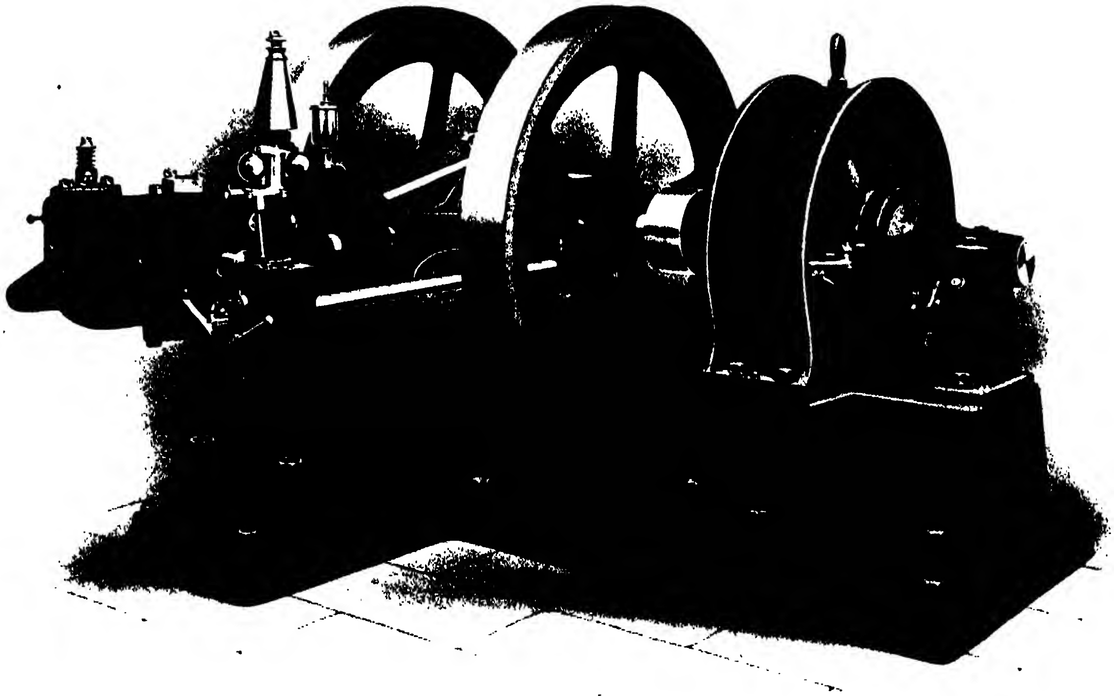


Fig. 385.—Crossley Oil Engine and Dynamo, forming a 3-Kilowatt Electric Lighting Plant

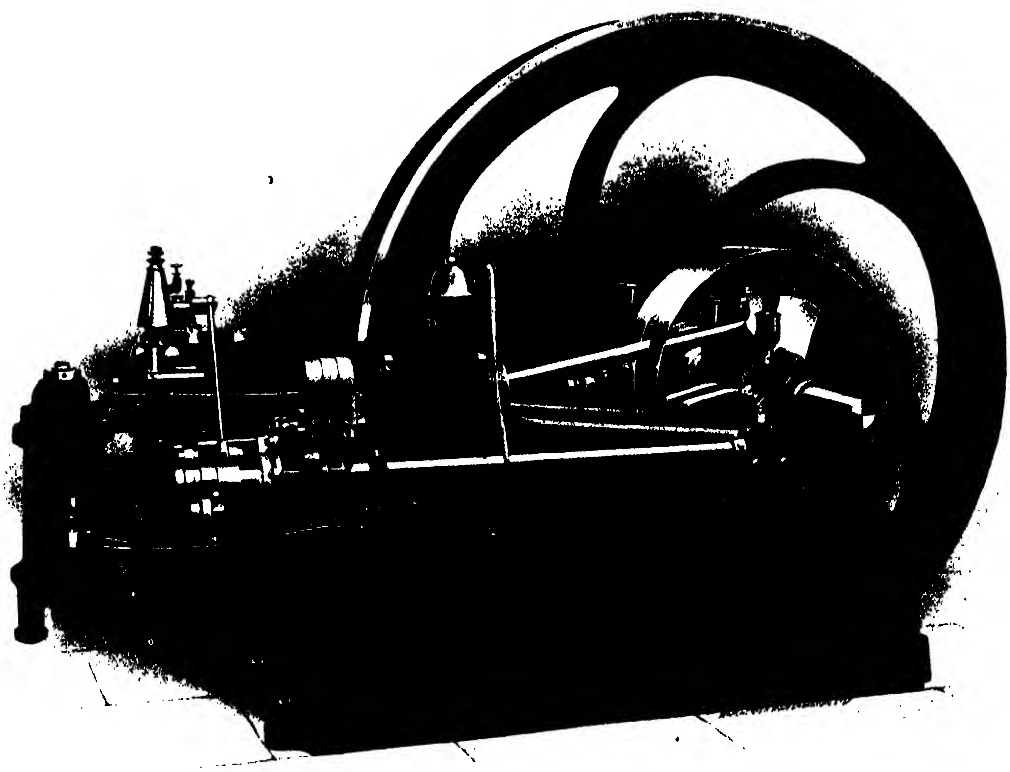


Fig. 386.—Crossley Oil Engine: with Exhaust-heated Vaporizer and Electric Ignition

of the valve mechanism. Fig. 384 illustrates a moderate-power type of Crossley oil engine in which any grade of refined or crude petroleum may be readily burned, and other examples are given in figs. 385 and 386.

Engines of a very similar construction are also manufactured by Messrs. Crossley for burning petrol or benzene, as illustrated in fig. 387, which shows an entirely self-contained portable engine of $3\frac{1}{2}$ b.h.p.

The Trusty Engine.—Vaporization of the oil supply takes place in this engine in contact with the inner surfaces of a heated chamber into which it is fed drop by

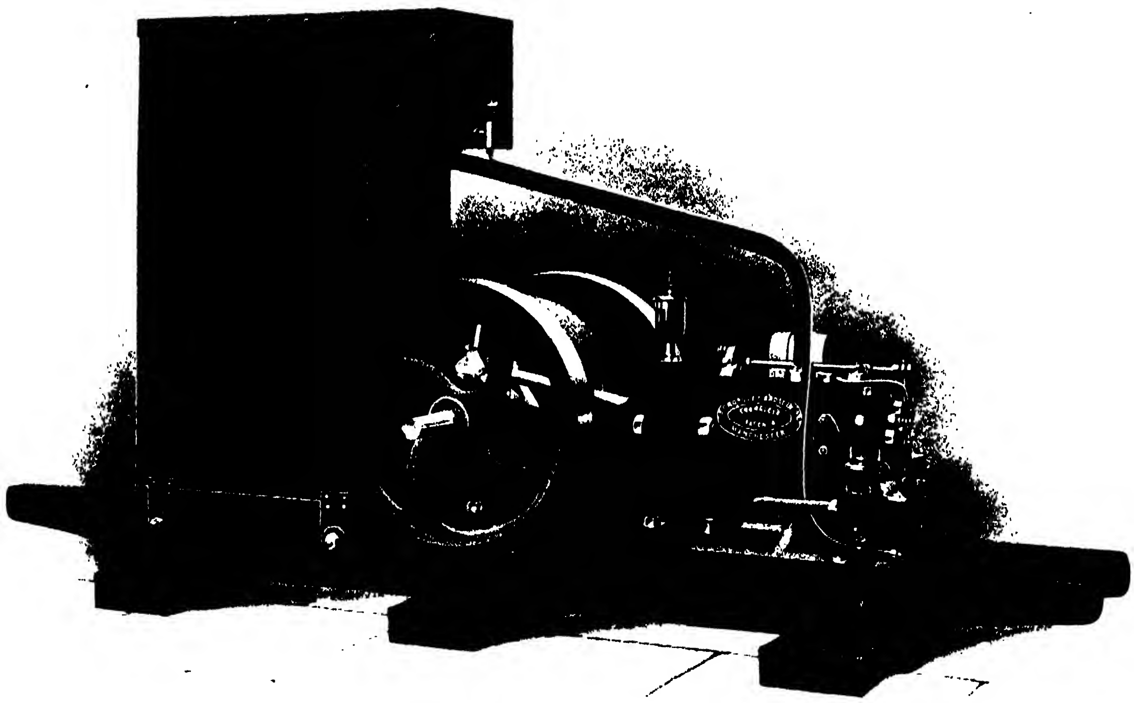


Fig. 387.—Crossley's $3\frac{1}{2}$-B.H.P. Portable Petrol or Benzine Engine

drop. Regulation of the speed is very efficiently done by means of an inertia governor acting on the admission valve and on the oil pump. When the speed exceeds the fixed limit the connection with the governor becomes interrupted, and as a result the admission valve not only fails to rise, but the vaporizer also cuts off the supply of the explosive mixture. Firing of the mixture is done in contact with a tube heated to redness by an oil lamp, the chimney of which is lined with an incombustible asbestos compound, which prevents the flame from becoming chilled by the metal surfaces, and also concentrates the heat of the flame upon the ignition tube. Before starting the engine it is necessary to heat the vaporizer for about twenty minutes, and there is the further disadvantage that the surfaces become rapidly covered with deposits of carbonaceous residues. These defects are balanced to some extent by the small consumption and by the possibility of using ordinary commercial oils of very variable quality with good results.

Griffin Engine.—The vaporizer of this engine is enclosed in the base of the engine, and is heated by the exhaust gases. Compressed air at a pressure of about 2 lb. per square inch is supplied by a small pump, and stored in a reservoir in the base of the engine. The compressed air passes from this reservoir to an atomizer nozzle, where it aspirates the oil and carries it over in the form of a cloud of fine globules. The oil in this condition arrives at the vaporizer at the same time as the air supply, which is sucked in from the atmosphere by the movement of the piston. A red hot tube serves for the ignition of the charge, and its temperature is maintained by a heater, which is fed with a mixture of air saturated with globules of the oil. The Griffin engine is both powerful and economical, and the consumption does not exceed 1 pt. per horse-power hour.

Niel Engine.—As in the majority of other oil engines, the essential feature is the vaporizer. In other respects the design is the same as, or very similar to, that of the gas engines built by the same makers. The vaporizer consists of a small brass chamber, provided with internal webs which offer a large heating surface to the oil; and the action is very regular, as the oil which is stored in a reservoir at a level of about 6 ft. above the base is spread in fine drops uniformly over the hot surface by suitably arranged guides. An automatic valve allows air from the outside to enter the vaporizer chamber, and by mixing with the oil vapour to form the explosive mixture. A special pipe from the reservoir conveys a supply of oil to a lamp which serves the double purpose of heating the vaporizer chamber and the ignition tube. To start the engine, which is not a long operation, the vaporizer requires to be heated with a wood-spirit lamp provided for the purpose.

Both the admission and exhaust valves are controlled by the governor, which at the same time suppresses the oil supply. This arrangement ensures regularity of working and a consumption at all times proportional to the power developed. Including the oil burned in the heater the consumption is about 1 pt. per horse-power hour.

Both horizontal and vertical types are constructed, but in the latter arrangement, which is known as the Atlas engine, the consumption is not so good. The governor is disposed with its axis horizontal; the compression is not carried beyond 4 lb., and from 45 to 70 pt. of water per horse-power are required for the cooling of the cylinder.

Diesel Engine. This very remarkable system has attracted much attention by reason of the excellent consumption results that have been obtained, and the novelty of certain features. It is an internal-combustion engine, working on a four-stroke cycle, with a very high initial compression of the air into which the oil is injected. Although the system of initially compressing the mixture to a pressure and temperature sufficiently high for self-ignition had been previously proposed, Mr. Diesel was the first to apply the system with advantage to a four-stroke cycle engine of real practical value.

The essential parts of the engine are—

1. A working cylinder in which the action takes place in the customary four stages, namely, (*a*) suction of the air supply; (*b*) compression of the air; (*c*) injection of the oil, combustion, slight compression, and expansion during the working stroke; (*a*) exhaust of the waste gases. All the valves, with the

customary cam gear for their operation, are carried on the upper cover of the cylinder, which is arranged in a vertical position.

2. A special pump, which forces the oil supply into a small chamber, from whence it is carried into the cylinder by a jet of air, and a second small pump, mounted on the frame, for supplying the air to the oil chamber at a pressure slightly in excess of that in the engine cylinder.
3. A governor controlling the action of the oil pump and varying the supply to the carburettor.

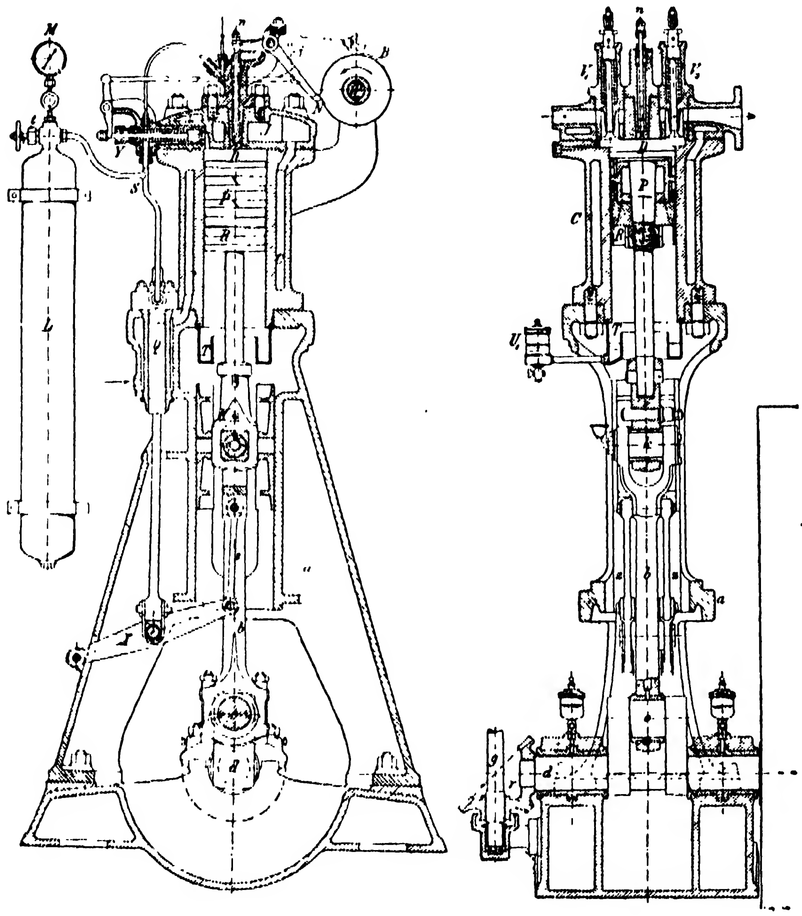


Fig. 388. Sectional Side and Front Elevations of Diesel Engine

In the designs of other makers of the Diesel engine the original vertical arrangement adopted by the Augsburg builders has been adhered to, with the piston working the crank through a connecting rod, from which the air pump is worked by means of the side levers shown in the illustration, fig. 388. Arrangements are provided for adjusting the stroke of the oil-pump plunger, and thus of varying the supply by hand or by the governor during the running of the engine. It appears that the regulation of the oil injection plays a very important part in the economy of the working. When the air in the cylinder is compressed to a pressure of 40 atmospheres, the temperature rises to 600° or 800° C., at which temperature the injected oil spontaneously ignites, provided always that the injection is effected at the correct moment and under the most favourable conditions. These conditions seem to be fully satisfied in the Diesel engine, which appears to work

THE DIESEL ENGINE

Index to the Principal Parts

1. Cylinder.
2. Water Jacket.
3. Engine Frame.
4. Sole Plate.
5. Piston Rings.
6, 7. Piston Bucket.
8. Piston Rod.
9. Piston.
10. Cross Head.
11. Cross-head Pin.
12. Cross head Bushes.
13. Cross-head Guide Pins.
14. Cross-head Guide Shoes.
15. Connecting Rod.
16. Connecting Rod Bottom End.
17. Bushes of 16.
18. Crank Pin.
19. Crank Webs.
20. Crank Shaft.
21. Bushes of Main Bearing.
22. Main Bearing.
23. Main-bearing Oil Cup.
24. Guide-bar Oil Cups.
25. Holding down Bolts.
26. Cylinder Cover.
27. Inlet-valve Box.
28. Valve-lever Bracket.
29. Spindle with Valve and Spiral Spring.
30. Gland.
31. Valve Lever.
32. Roller.
33. Inlet-valve Cam.
34. Air-inlet Valve Cam.
35. Air Inlet.
36. Oil-valve Box.
37. Valve-lever Bracket.
38. Oil-jet Needle.
39. Valve Lever.
40. Laminated Oil-valve Spring.
41. Oil-valve Cam.
42. Nose of Cam 41.
43. Air-inlet Valve Box.
44. Valve-lever Bracket.
45. Spindle with Valve and Spiral Spring.
46. Valve Lever.
47. Gland.
48. Valve Connecting Rod.
49. Valve Crank.
50. Air Pipe.
51. Gland.
52. Air Pipe.
53. Valve-cam Roller.
54. Nose of Cam 34.
55. Oil-feed Pipe.
56. Exhaust-valve Box.
57. Valve-lever Arm.
58. Exhaust-valve Lever.
59. Contact Roller.
60. Exhaust-valve Cam.
61. Nose of Cam 60.
62. Auxiliary Exhaust Cam.
63. Nose of Cam 62.
64. Valve Cam.
65. Valve-shaft Bracket.
66. Valve-shaft Bearings.
67, 68. Valve-shaft Bevel Gears.
69. Upper-bearing Bevel-gear Shaft.
70. Bevel-gear Shaft driving Valve Shaft.
71, 72. Bevel Gears.
73. Lower Foot Bearing for 70.
74. Adjustable Bracket for 73.
75. Bracket carrying 69.
76, 77. Bracket-seat Facings.
78. Hand Reversing Lever.
79. Cylinder Flange.
80. Engaging Pin of Hand Reversing Lever.
81. Groove in Sleeve with which 80 engages.
82. Notch in Flange.
83. Retaining Pawl pivoted on Bracket 65.
84. Cast Bracket on Engine Frame.
85. Jacket-water Exit.
86. Air-pump Plunger.
87. Connecting Rod.
88. Connecting-rod Head.
89. Cross Pin.
90. Double Side Lever.
91. Driving Radius Link.
92. Air-pump Cylinder.
93. Cylinder Cover.
94. Air-discharge Valve.
95. Air Pipe between the Pump and the Air Receiver.
96. Oil-holder.
97. Guide Bars.
98. Bearing for Lever 90.
99. Outlet for Exhaust Gases.
100. Flywheel.

better on oils than on ordinary lighting gas. Experiments are also being made with a view to using producer gases. It may be stated, however, that the Diesel engine runs well on all petroleum oils, from the light benzene varieties having a density of 0.70 to the heavier oils of 0.85 density. Mr. Denton of New York has even succeeded in

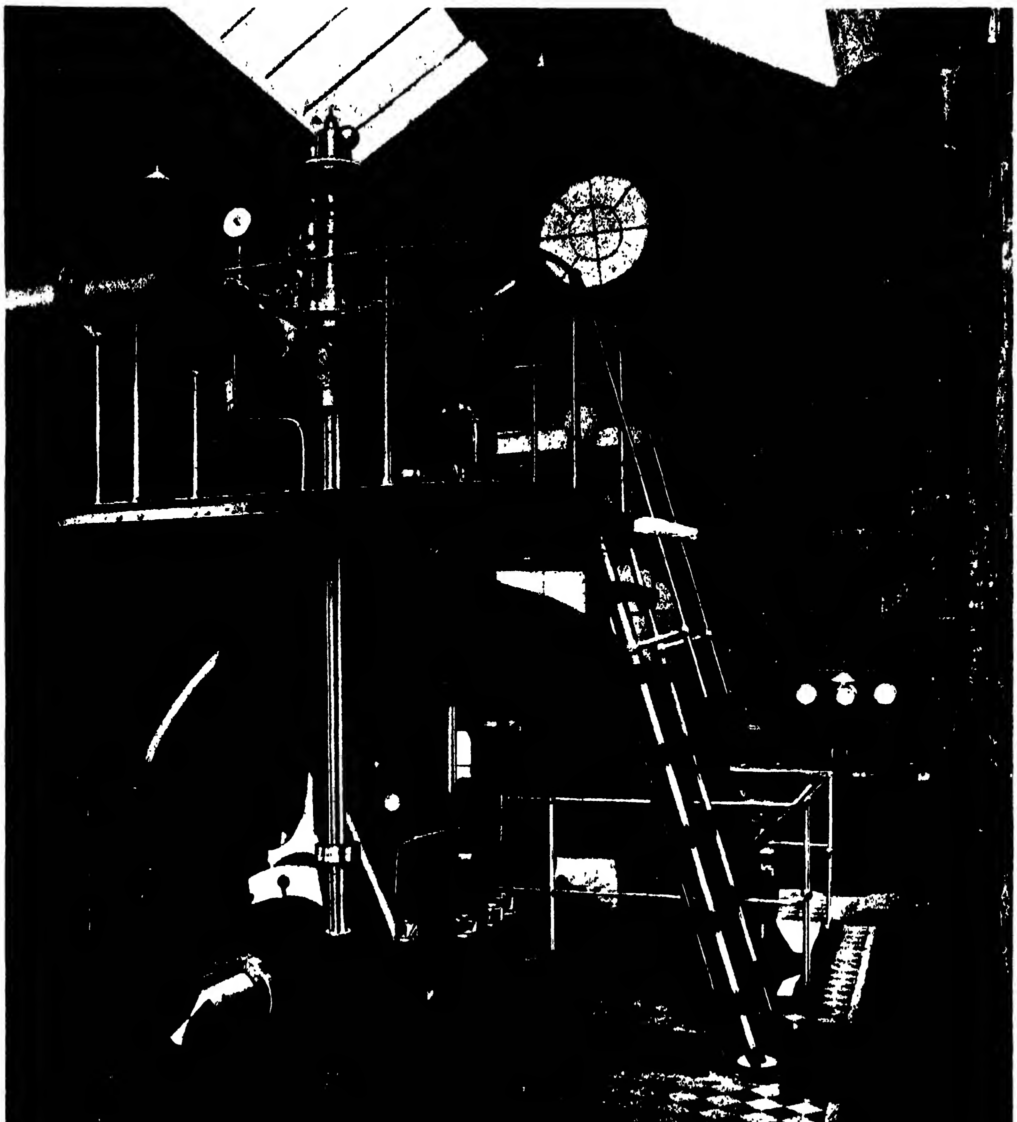


Fig. 389.—Diesel Engine, 80 H.P., coupled to Electric Generator

working satisfactorily with heavy viscous residues of 0.88 density and Russian oil of 0.905 specific gravity. These oils, without exception, burn completely in the highly compressed air contained in the Diesel engine cylinder, and the surfaces do not become covered to any serious extent by objectional deposits.

Fig. 389 illustrates a Diesel engine of 80 b.h.p. directly connected to an electric generator. For higher powers two or more engines are arranged side by side as shown in figs. 390 and 391, which represent engines of 160 and 400 b.h.p. respectively.

GAS PRODUCERS

The development of gas and oil engines has been traced in the previous sections, step by step, from the first practical attempt of Lenoir to the present day, when, as a result of this continued progress, the gas engine, and in many cases the oil engine,

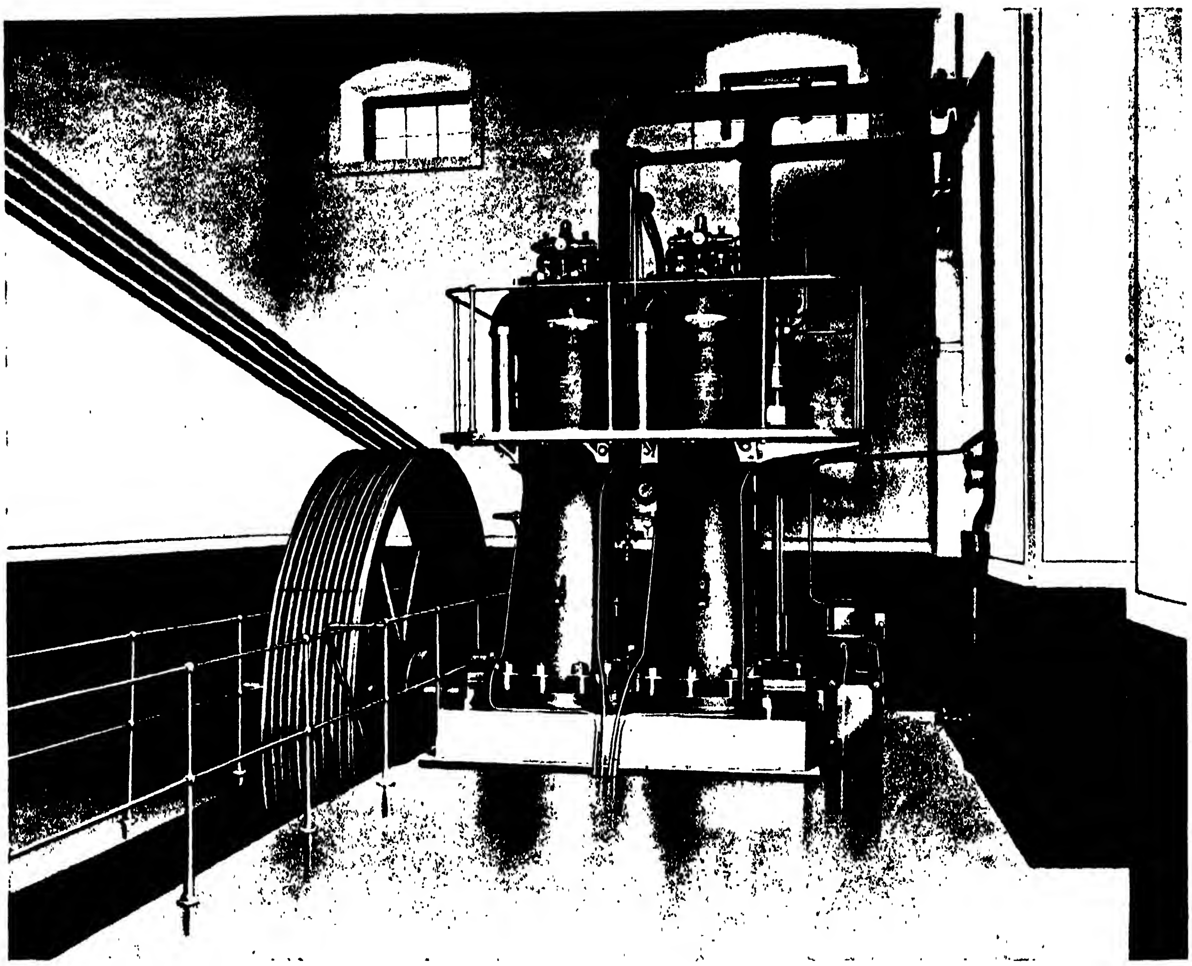


Fig. 360. Diesel Engine, 100 H.P.

is able to compete successfully on more than equal grounds with the steam engine. In certain districts the price of illuminating gas is so great as to prohibit its use for power purposes in competition with steam. To overcome this difficulty, attempts were first made to make the gas engine suitable under even these conditions, by increasing the expansion and the initial compression, and thus reducing the consumption. Light hydrocarbons vaporized in the cold condition by a stream of air were also used to replace the costly illuminating gas; and, finally, special vaporizers suitable for the heaviest classes of oils were devised; but in spite of all this the cost of the power produced was considerable compared with steam. In those districts where the price of town gas was prohibitive, special gas plants were installed by manufacturers to meet their

individual requirements, but it was only on the introduction of water gas, and later of producer gas, that the very economical results of the present day became possible.

Water gas is a mixture of combustible gases resulting from the combustion of carbon in presence of steam vapour. The combustible portion of the gas consists largely of carbonic oxide, CO, sometimes called air gas, which results from the combustion of the coal in air. When a jet of steam is passed into the hot mass of coal the steam becomes dissociated into its elements, hydrogen and oxygen, which then combine with

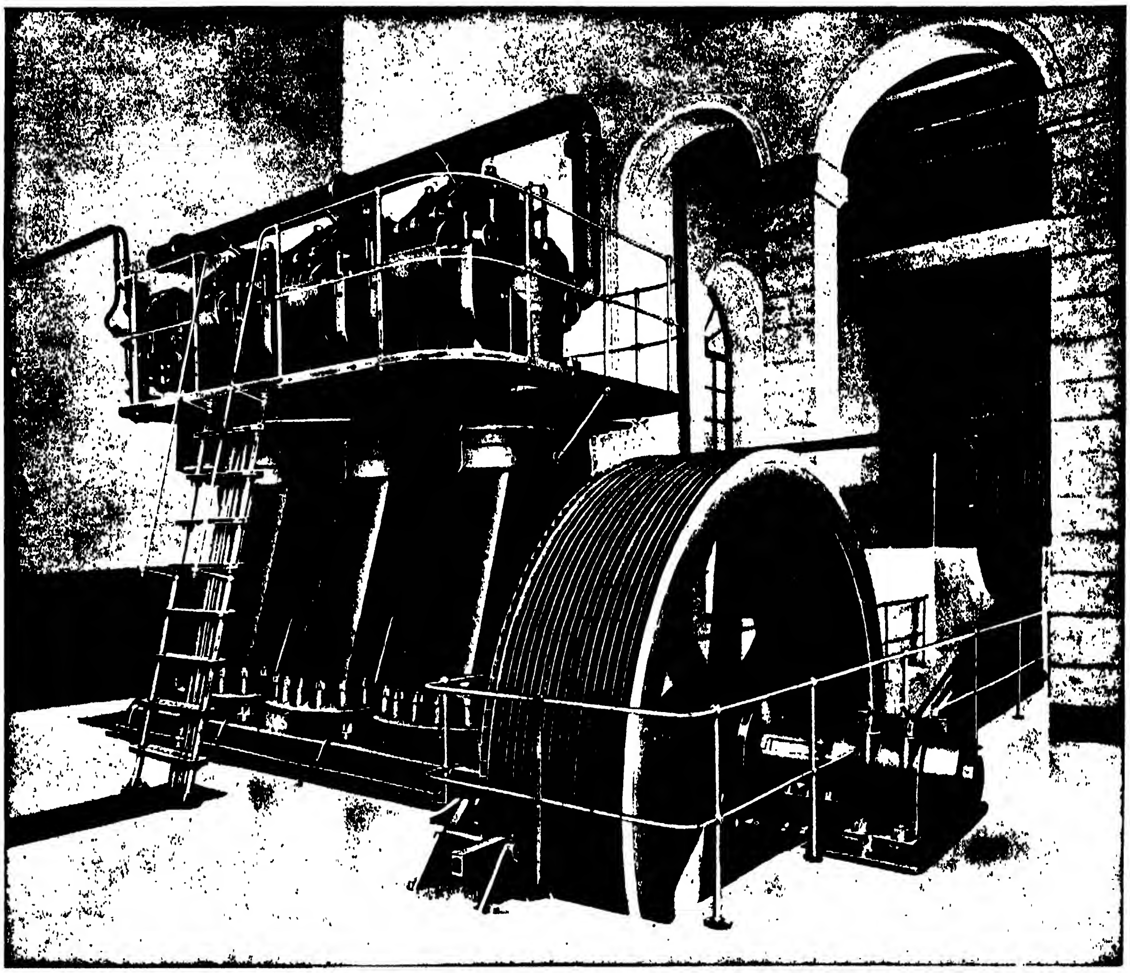


Fig. 391.—Diesel Engine, 400 H.P.

the carbon to form an additional quantity of carbonic oxide and marsh gas, CH_4. Expressed by a chemical formula the action is as follows:—

$$C + H_2O = CO + 2H$$
$$\text{and } 3C + 2H_2O = 2CO + CH_4.$$

That is, the combination of carbon, air, and steam at a high temperature results in the production of an inflammable mixture of carbonic oxide, CO, hydrogen, H, and marsh gas, CH_4, diluted by the incombustible nitrogen contained originally in the air. Owing to the cooling effect of the steam, which tends to reduce the temperature of

the fire below the point necessary for the chemical combination, the action must be made intermittent, so as to allow the temperature to recover after each steaming period. By using superheated steam the duration of the steaming period may be considerably prolonged, as the fire has not then to supply so much heat for its dissociation. Water gas suitable for combustion in gas engines may contain as much as 57 per cent of hydrogen and 28 per cent of carbonic oxide; but the proportions may be varied by regulating the proportions of the steam and air. The following is an analysis of a sample of water gas having a calorific value of about 7500 B.T.U.:—

Hydrogen	49.2 volumes
Marsh gas	0.3 ,,
Carbonic oxide	43.8 ,,
Carbon dioxide	2.7 ,,
Nitrogen	4.0 ,,
	100.0 volumes.

Owing to its high illuminating value, water gas has been largely used for public lighting, particularly in certain German and American towns, and many different arrangements of the plant have been devised by various manufacturers. Of these the best known are probably those of Strong and Lowe, which consist essentially of a metal casing lined with refractory firebrick to withstand the intense heat of the burning coke. When the fuel is brought to an incandescent condition the blast of air is cut off, and a jet of steam, preferably superheated, is admitted. At the high temperature existing in the chamber the vapour dissociates into its elements, hydrogen and oxygen, which combine with the carbon, as already explained. The mixture of combustible gases then passes away to the purifiers, and thereafter to the engine.

When the temperature becomes so far reduced, by the cooling effect of the steam, that the action diminishes, it is necessary to revive the fire by cutting off the steam and by applying the air blast. The process thus involves alternately-repeated steaming and blowing, the latter stage being necessary to prevent the temperature of the fire from being reduced below the point of combination. About 16 cu. ft. of water gas are produced by the combustion of 1 lb. of coke.

Two analyses of samples of water gas, produced by the Strong and the Lowe plants, show the following compositions of the mixtures:—

1. Strong water gas (analysed by Morse)

Hydrogen	53 volumes
Carbonic oxide	35 ,,
Hydrocarbons	4 ,,
Inert gases	8 ,,
	100 volumes.

2. Lowe water gas (analysed by Professor Remsen)

Hydrogen	30 volumes
Carbonic oxide	28 ,,
Hydrocarbons	34 ,,
Inert gases	8 ,,
	100 volumes.

It is possible to completely suppress the action of the steam on the fire by blowing dry air over the fire in the proportions necessary for combustion. A gaseous mixture of 34 volumes of carbonic oxide and 65 of nitrogen, having a calorific value of 3000 B.T.U.'s, is formed, and the proportion of carbon dioxide is reduced. To this gas is given the name of the German scientist, Siemens, who first experimented with it. When the fire is blown for about ten minutes with the air blast, and then the steam is applied, the mixture of the two gases produced has an average composition of 10 parts of hydrogen to 28 of carbonic oxide and 50 of nitrogen, with a calorific value of 5500 B.T.U.'s. 1 lb. of fuel serves for the production of 87 cu. ft. of the mixture measured at atmospheric pressure. Instead of developing air gas and water gas alternately, and then mixing them, the apparatus may be so arranged as to simultaneously generate the two kinds of gas without necessitating the intermittent action. The gas developed in this way is called "poor" gas or "producer" gas.

Two French engineers, Thomas and Laurens, were the first to exhaustively study the problem of economically generating poor gases, and to construct a suitable apparatus; but just as Otto applied the principles of the gas engine, as laid down by Beau de Rochas, so did Siemens bring the gas producer to a rational form and practically apply it to the industries of the world—more particularly to the manufacture of steel and other metals. Siemens's arrangement forms the basis of the majority of the gas producers that have been designed for use in conjunction with gas engines of larger powers. The most typical of these producers will now be described in some detail.

Dowson Producer.—This system was introduced shortly after that of Siemens, and since that time it has been very extensively applied to many industrial services. Five distinct sections of the Dowson plant, fig. 392, may be distinguished as follows: The generator, the steam superheater, the tar extractor, the scrubber, and the gasometer. The generator, in which the fuel is consumed, consists of a vertical cylindrical chamber A lined with refractory firebrick. Grate bars B at the bottom of the chamber support the fuel, which generally consists of ordinary English anthracite, and during the working of the apparatus the new fuel is added as required through a covered funnel A′ at the top of the chamber and a special gas valve *a*, which must not be opened simultaneously. By these means air is prevented from entering the chamber while stoking, as otherwise there would be serious danger of explosion.

About 35 cu. in. of steam, reckoned at atmospheric pressure, are allowed for each brake horse-power developed by the engine, and a heated spiral serves for the superheating of the steam which becomes dissociated in the generator. Both steam and air are supplied simultaneously, the latter being entrained by the steam in its passage through the nozzle of an injector. Sufficient heat is developed by the combination

of the oxygen of the air and the carbon of the fuel to decompose the superheated steam into its constituent elements, and as a result a combustible mixture of air gas and water gas is obtained for use in the engine or as otherwise required. By regulating the action of the injector the quantities and proportions of the air and steam admitted to the generator, and the quality of the resulting mixture, may be varied as desired. From the generator the gases pass into the tar extractor and water valve, which determines the pressure that is maintained in the gasometer. It consists of a box divided into two portions by a vertical hanging partition, which

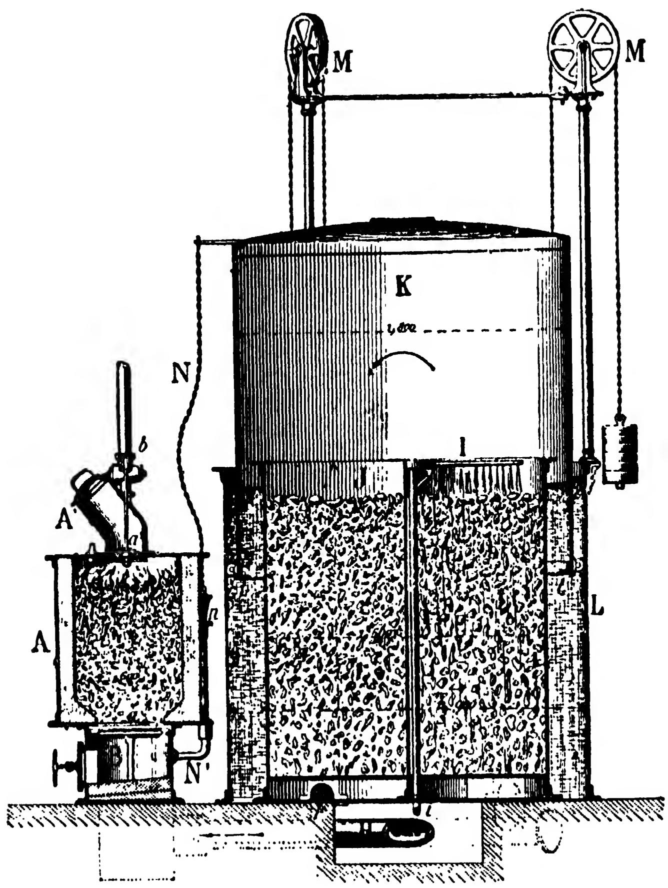


Fig. 302. - Dowson Gas Producer

dips into a water seal. It is the difference of the water-level on the two sides of the partition that determines the gasometer pressure. The gas is then cooled and washed in a scrubber filled with coke, over which water is continuously showered; and the last impurities are extracted by passing the gas through wet sawdust before admitting it to the gasometer. From numerous analyses made by Dowson and Witz the average composition of the mixture of gases may be taken as being about $\frac{1}{4}$ of hydrogen, $\frac{1}{6}$ to $\frac{1}{4}$ of carbonic oxide, and $\frac{1}{2}$ of nitrogen, with a mean calorific value, which varies with the quality of the fuel, of from 5300 to 6000 B.T.U. It must not be forgotten that the mixture has only one-quarter the richness of ordinary town gas; but as the cost of its production is about $\frac{1}{6}$ to $\frac{1}{10}$, the economy resulting from the use of the former is considerable. An economy as high as 77 per cent is obtainable with a consumption of 6 oz. of English anthracite per horse-power hour.

Many arrangements of grates have been devised to overcome the difficulty that is often experienced in removing the ash and in preventing the formation of clinker, which quickly reduces the action of the fire. In the arrangement shown in fig. 393 the air

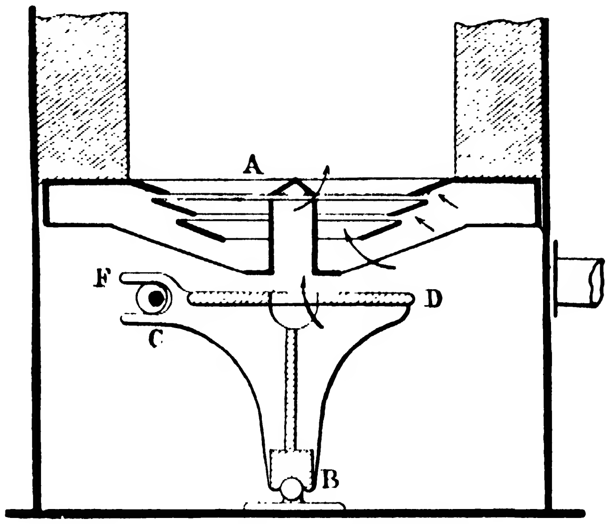


Fig. 393.—Gas-Producer Oscillating Grate

enters through the inclined grate bars A, and the accumulation of ash and clinker is prevented by shaking the mass of fuel which rests upon the rocking plate D. This plate is rocked about the pivot B by means of the rotating cam C, which engages with

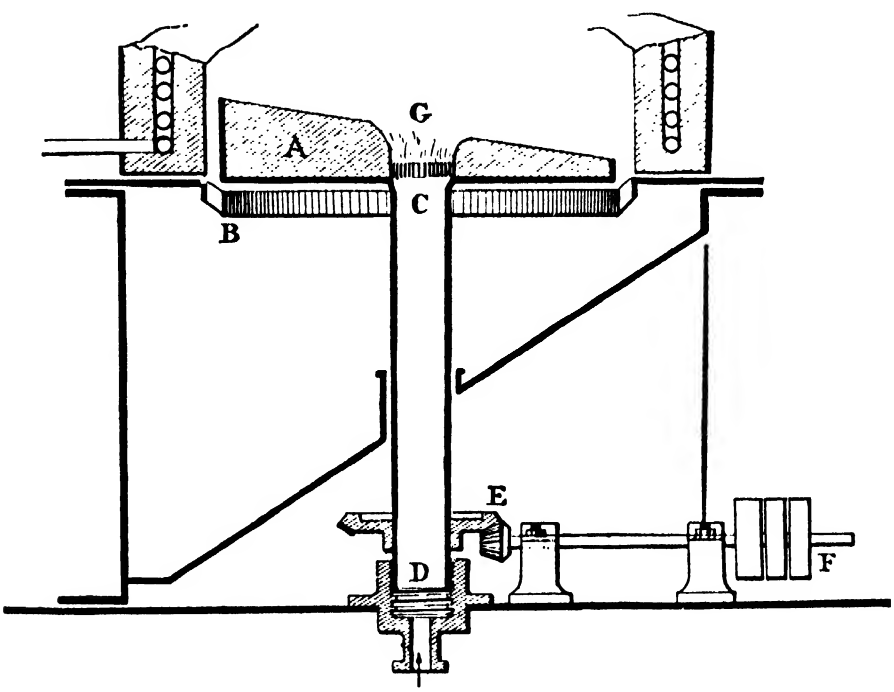


Fig. 394. Gas Producer Rotary Grate

the fork F. Another arrangement is the rotary grate illustrated in fig. 394. A section of the inclined base plate, lined with refractory material, which carries the fuel is shown at A. It is rotated by means of the horizontal driving shaft F and the bevel gears E.

Air is supplied to the grate through the grate spindle C D, which is made of a tubular form.

Buire-Lencauchez Producer.—The gas generated has a percentage composition of—

Carbonic oxide	29.4
Carbonic acid	5.9
Hydrogen	17.6
Nitrogen	47.1
	100.0

Theoretically 1 lb. of carbon should produce 85 cu. ft. of gas at 0° C. and atmospheric pressure having a calorific value of 5350 B.T.U. From actual results 13,400 cu. ft.

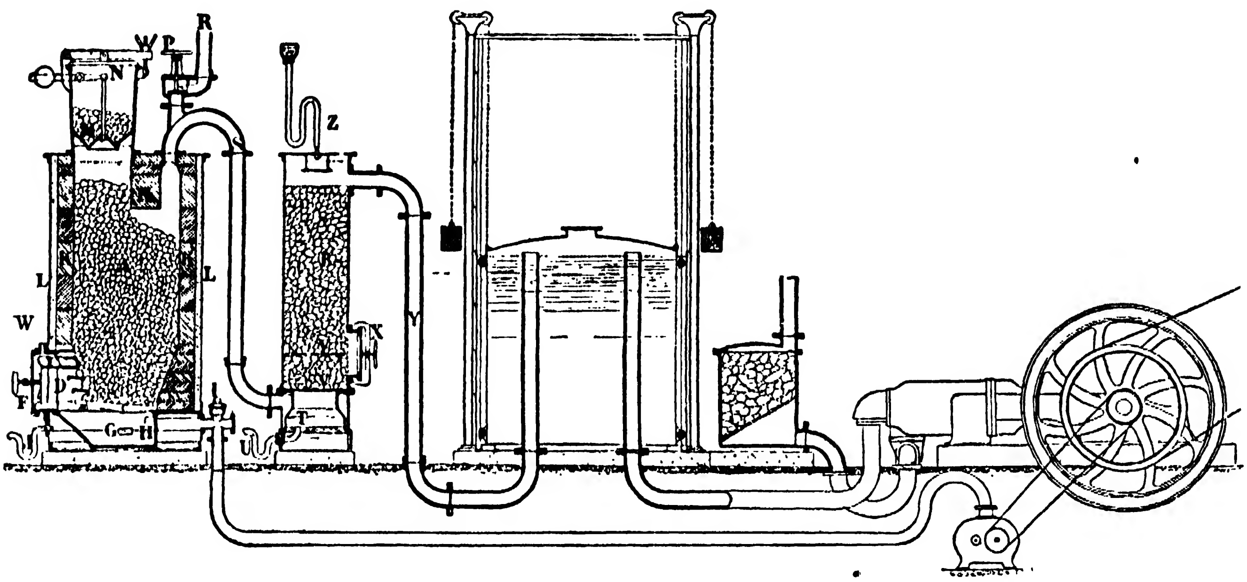


Fig. 395.—Sectional Arrangement of Buire-Lencauchez Producer Plant

of gas were produced from 160 lb. of carbon, and from these figures the economy of the producer and the quality of the gas may be calculated. Excellent results have been obtained from the Lencauchez producer as manufactured by Messrs. Buire, of Lyon. In one important point the system differs from the Dowson arrangement in the absence of a special steam generator, and thus the special and continual supervision of the water supply is dispensed with. Fig. 395 shows the arrangement of the plant and sections of the various parts. A is the generator, lined with refractory firebrick, and further protected by a thickness of sand between the inner lining K and the outer sheet-metal casing L. The supply of fuel is placed in the hopper on the top of the generator, and is admitted through the inverted cone M, which may be lowered from the outside by means of the balanced lever N, while the cover of the hopper remains hermetically closed. Communication between the atmosphere and the interior of the generator is in this way prevented, and all danger of explosion thus avoided. The fuel, either non-caking coal or anthracite, is carried on grate bars, which separate it from the enclosed ashpit, and a constant fine stream of water is

allowed to trickle into the pan, where it rapidly becomes vaporized by the radiation of heat from the fire bars. The steam thus formed is carried by the blast of air from the fan into the generator, where it is dissociated in contact with the incandescent fuel. An overflow syphon J preserves a constant level of water in the ashpan. The necessity of using the centrifugal air fan, driven by the engine itself, is a disadvantage which is compensated to some extent by the absence of the separate steam generator used in the Dowson arrangement. As the gas is formed it passes through the pipe S and the water seal T, which prevents its return to the generator from the scrubber R. This scrubber or washer is filled with coke, the weight of which is carried upon perforated diaphragms V V, while water in a constant stream is allowed to percolate through the mass, from the supply pipe Z at the top of the scrubber down to the bottom chamber T, from which it overflows through the bent pipe U. In its passage through the scrubber the impurities are retained by the water, and the gas becomes thoroughly washed before its admission to the gasometer. When the gasometer becomes filled with the gas, and reaches the top, it acts upon a lever, which cuts off the air supply to the generator, and thus reduces the production until the gasometer falls, when the air is again supplied to the generator. By these means the supply of gas is made to vary with the demands of the engine. In front of the grate bars is placed a range of jets supplied with gas from the gasometer, by means of which the fire may be started or revived after a temporary stoppage of the plant, and a certain economy is obtained by the utilization of the waste heat of the gases, which are caused to impart some of their heat to the air in its passage to the generator through a tubular reheater. In general, for a 60-h.p. plant, developing 7000 cu. ft. of gas per hour, about 22 gal. of water are required for the steam supply to the generator, and about 110 gal. in the scrubber. The water from the cooling jackets of the engine cylinder may be used for the purpose, provided it is first cooled in a suitable reservoir, through which it must be circulated by a pump.

Messrs. Matter & Co., of Rouen, have installed several large plants of 2000 h.p., consisting of Buire-Lencauchez producers and Simplex gas engines, which together have given very economical results, due largely to the possibility of using cheap qualities of "poor" French coal in place of English anthracite.

Gardie Producer.—Highly-compressed air at from 13 to 15 lb., mixed with steam at the same pressure, and therefore at a considerable temperature, is used in this producer, as the high temperature and pressure are found to improve the action. The fuel is carried upon a firebrick base, which dispenses with the ordinary arrangement of fire bars, and the supply of air and steam is admitted to the producer chamber through a ring of tuyeres. Observation holes are also provided at this same level, through which the state of the fire may be examined. A hopper, provided in the usual manner with a cover and coned base, serves for the introduction of the fuel, and the heat of the escaping gases is usefully employed in heating the steam supply as it circulates through a special heating coil. The gases then pass to a gasometer, through a simple type of scrubber consisting of two concentric tubes of unequal height. Use is also made of the waste heat of the gases for heating the air which is forced into a reservoir by means of a separate air pump. Some economy is thus effected by utilizing heat that would other-

wise be lost, and the use of the hot air permits of the injection of a larger proportion of steam. Several ingenious features are thus introduced in the Gardie producer, which is illustrated in fig. 397, and the gas obtained is of a rich quality, having a calorific value of about 5500 B.T.U. Owing also to the very small proportions of tar and ammonia by-products it is possible to dispense with the washing and scrubbing arrangements essential to other systems. One disadvantage of the system lies in the necessity of providing a special compressed-air reservoir and pump, which absorbs some of the

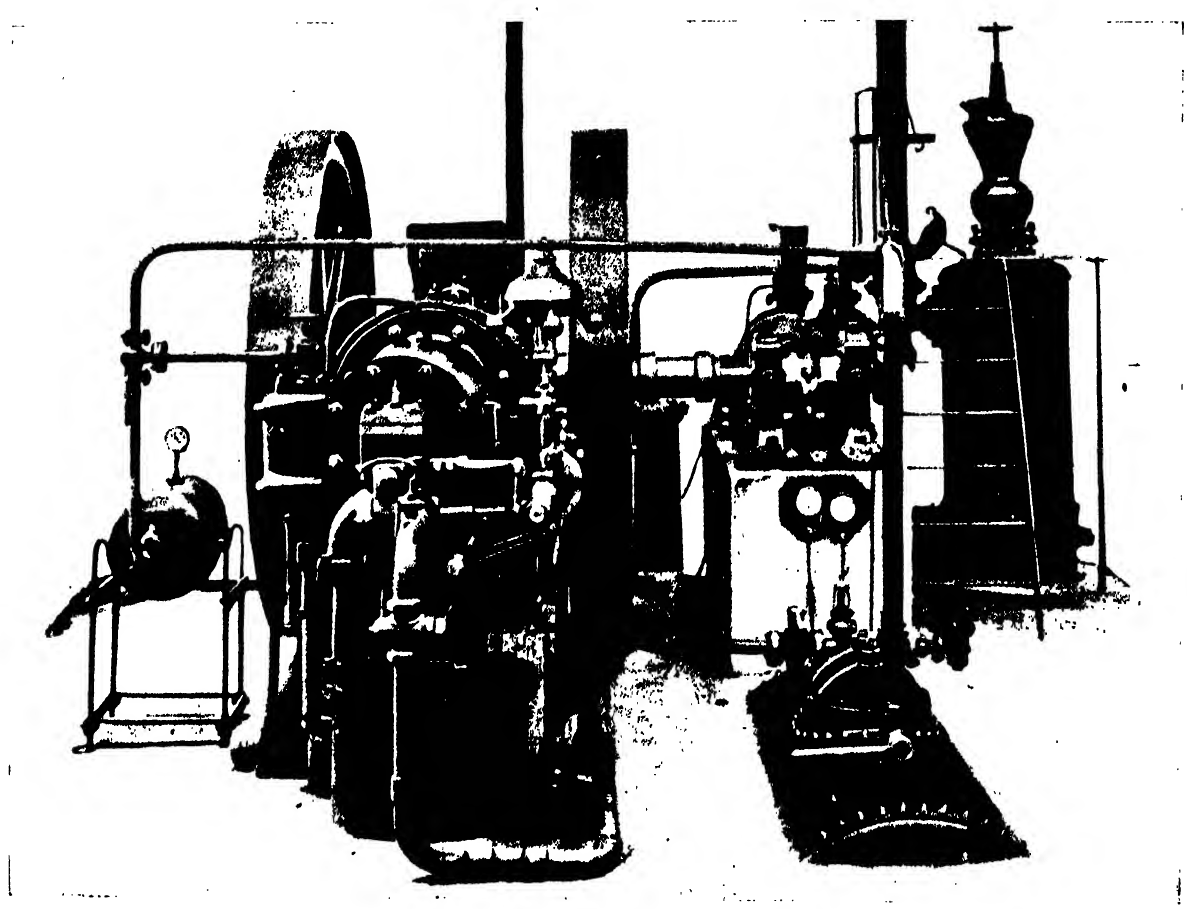


Fig. 396.—Installation of Gardie Gas Producer and Charon Producer-Gas Engine

power and introduces complication. A small installation comprising the Gardie producer plant and a Charon producer-gas engine is illustrated in fig. 396.

Taylor Producer.—Future developments of gas-power plants, and particularly of large units, depend upon the production of a suitable gas at a sufficiently low price, as the cost of town gas is in the great majority of cases prohibitive; and the problem has been attacked with considerable success by numerous inventors, who have endeavoured to devise plant capable of economically generating large volumes of gas suitable for use in explosion cylinders of engines by the dissociation of steam in contact with incandescent fuel. Taylor's generator may be taken as an example of one of the most perfect of the arrangements that have appeared within recent years, and one that has given satisfaction wherever installed in the metallurgical, glass, and other industries. In its usual form it consists of a gas generator, a boiler for the production of steam, a tubular

reheater, a series of cooling tubes, a tar extractor, a cleanser or scrubber, and lastly a scrubber. In the Taylor arrangement there is introduced a characteristic feature consisting of a rotating grate which automatically cleans the fire and permits of the clinker on the bars being removed without interfering with the action of the plant. It is possible also to use less anthracite or cheaper qualities of coal. As shown in the illustration,

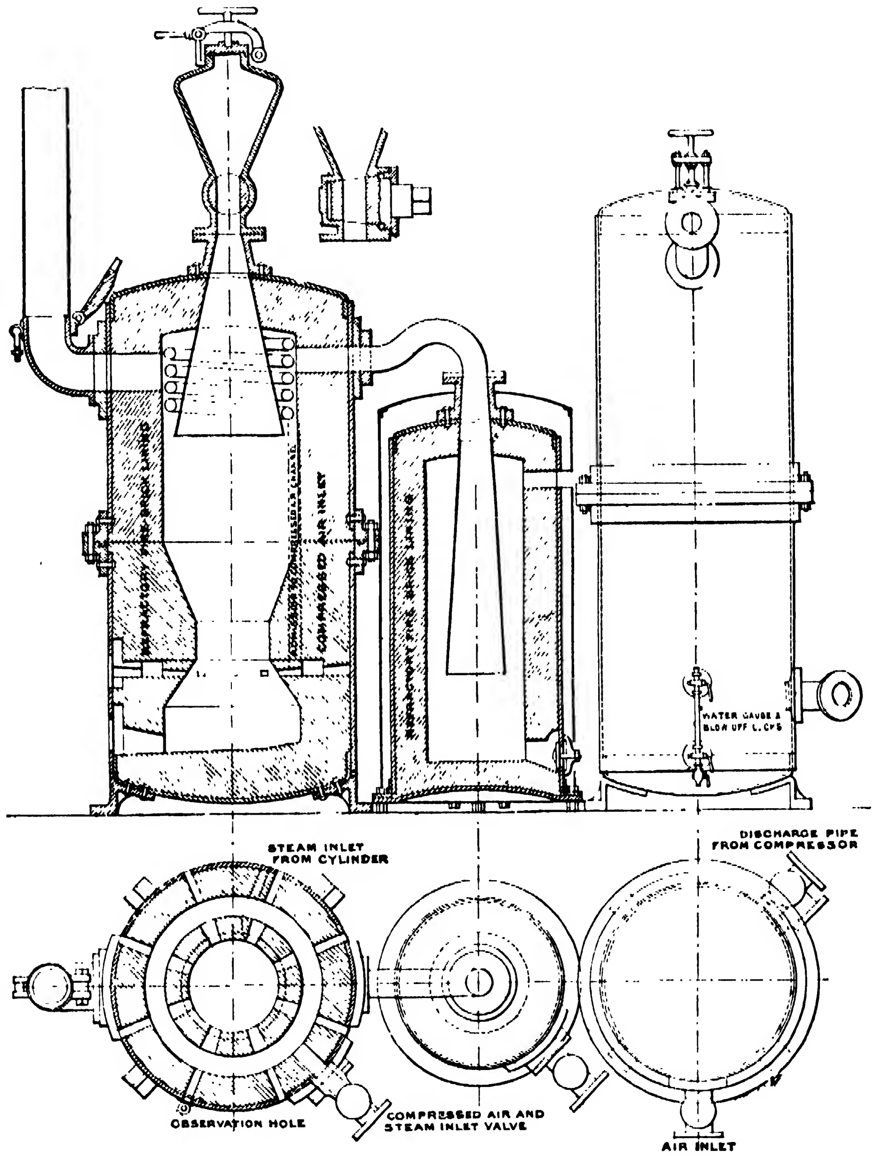


Fig. 397.—Sectional Elevation and Plan of Gardie Producer

fig. 398, the steam generator is placed above the producer in contact with the hot gases. After leaving the boiler the steam passes through a superheater placed in the course of the gases, and is mixed with air at a temperature which ensures increased economy when injected into the producer. On the other hand, the gaseous products resulting from the decomposition of the steam pass through a series of vertical cooling tubes having a large surface, then through the water in the extractor, where it is washed, and finally through the scrubber to the gasometer.

Mond Producer and Recovery Plant.—It is profitable in the case of large producer plants to install apparatus for recovering the ammonia produced, which has a considerable commercial value.

As shown in the sectional arrangement, fig. 399, the plant consists essentially of the producer, the condensing apparatus, and the ammonia-recovery towers and tanks.

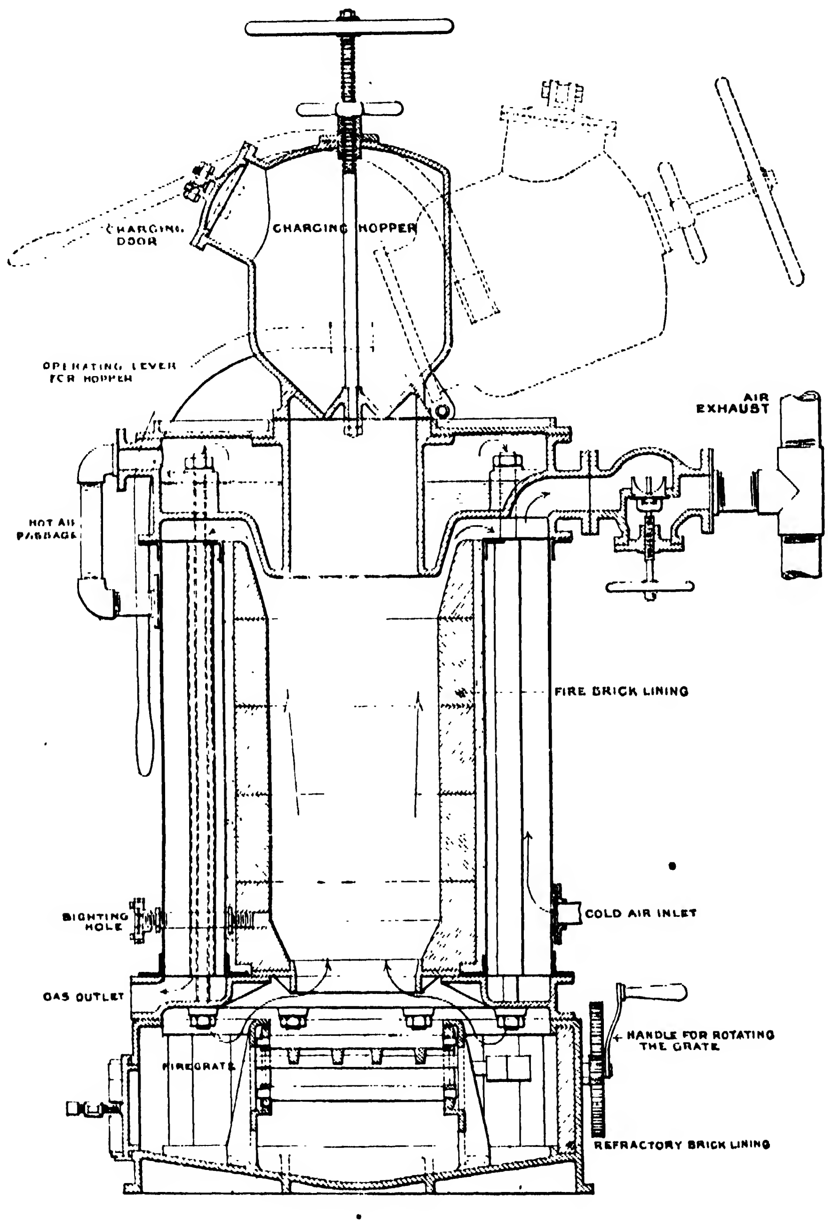


Fig. 398. Taylor Duplex Producer: Sectional Elevation

In the illustration A is the regenerator, in which the waste heat of the gases is utilized in heating the air and steam supplied to the generator; B is the washer; C is the tower in which the air supply is saturated with moisture; D is the gas-cooling tower, and E is the ammonia-recovery tower.

Sulphuric acid stored in the tank I is supplied to the settling tank J for the purpose of converting the ammonia contained by the liquor into sulphate of ammonia, which settles in the tank and is then removed.

The unprecipitated liquor is returned to the top of the ammonia tower by means of the circulating pump K.

Air is forced through the heating tower C and the regenerator A to the producer by the blower F, shown immediately under the mechanical washer B.

Bénier Producer. Since the time of the Paris exhibition in 1889, when a Simplex engine, driven by Dowson gas, was exhibited, it has been recognized by engineers that the future of the gas engine was dependent upon the development of the gas producer,

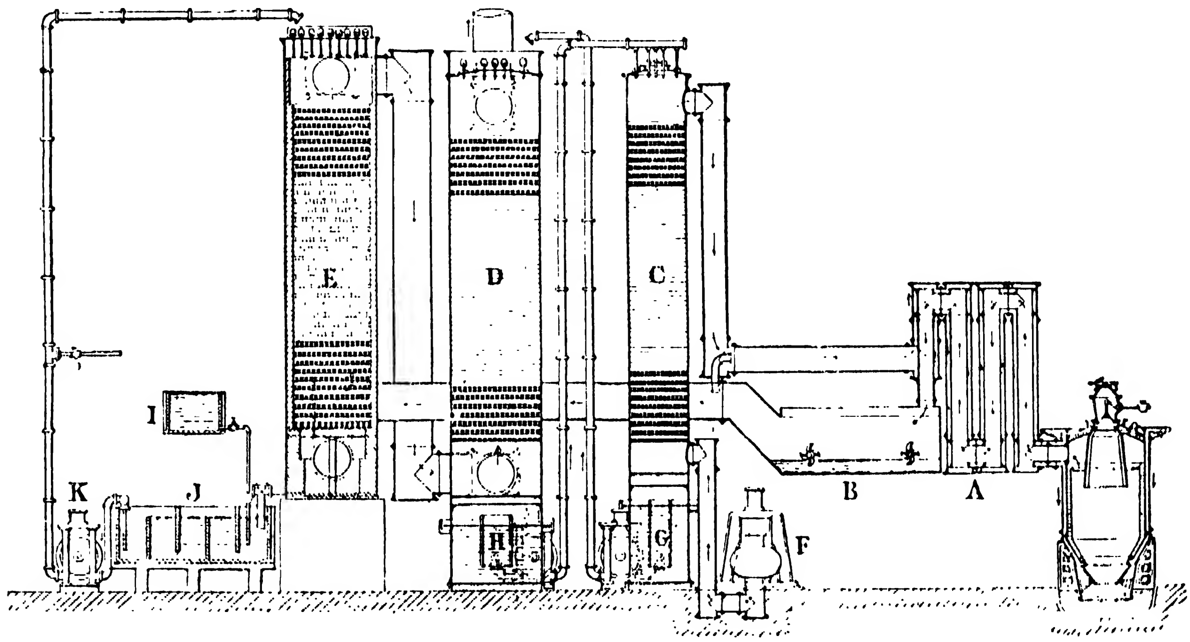


Fig. 399.—Mond Producer and Ammonia-Recovery Plant

and if the number of large installations is not so great as might be expected, the reason is probably due to the following disadvantages of the pressure system:—

1. Owing to the production of the gas under some pressure, there is considerable danger of the attendants being poisoned in the event of the escape of the very poisonous carbonic oxide gas, and it is necessary, therefore, to install the plant in an open situation.
2. Irregularity in the production of the gas necessitates the use of cumbersome and costly gasometers.
3. Continuous skilled supervision is necessary to maintain the regularity of the action.

These objections have been largely overcome in the Bénier plant, fig. 400, in which the gas is produced at a pressure lower than that of the atmosphere, so that all danger of the escape of poisonous gases is avoided, and the plant may be installed in any enclosed place, or near dwelling-houses. Further, the use of steam at atmospheric pressure ensures greater regularity in the production of the gas. In the case of pressure plants the irregularity is largely due to the difficulty of maintaining a constant pressure of

the steam, and accordingly of keeping the air and steam in their correct proportions. Orifices of a fixed size are provided for the admission of the air and steam, which are therefore sucked in always in the same proportions. Diagrams taken from the engine when running under a constant load show practically no variations even when taken at considerable intervals of time, and no regulation of the air and steam supplies is required once the sizes of the orifices have been determined. Very careful and frequent adjustment of the proportions of the air and steam is necessary in the case of pressure plants, to ensure a constant quality of the mixture and uniform working of the generator, so that skilled attention is required; whereas a suction plant of the Bénier type can be run by an unskilled labourer. The Bénier producer has given very economical results, due largely to the regularity of the action, and to the superheating of the air

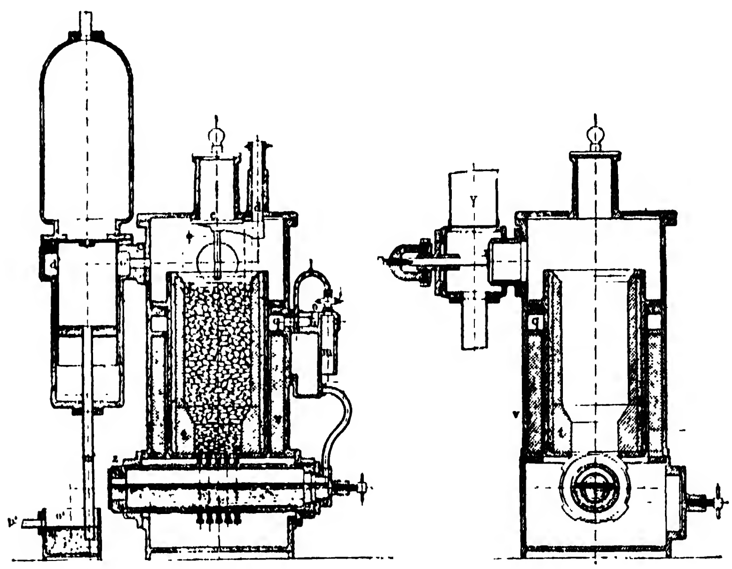


Fig. 400. Benier Suction-Gas Producer

and steam before its admission to the generator. Labour is reduced to a minimum by the use of a rotary grate, which is cooled by a stream of water. This arrangement permits of the fire being thoroughly cleaned without interfering with the normal running of the plant; and the life of the fire bars is greatly increased, as their temperature does not reach the point at which the metal is attacked.

A sectional elevation and plan of the Bénier suction-gas plant is given in fig. 401, which shows the arrangement of the producer and the engine. The engine works on the six-stage cycle proposed by Dugald Clerk, Benz, and Ravel, and in principle it does not sensibly differ from these earlier types. A special cylinder attached to the working cylinder serves as a compressor, and the cranks are set at 90° to one another. The pump is double, that is to say, it has two pistons, one for the suction of the air supply and the other for the gas from the producer. Two pipes carry the air and gas to a mixing chamber placed at the top of the cylinder and provided with a retaining valve. When the piston has completed five-sixths of its outward stroke it uncovers two exhaust ports in the cylinder walls, and these ports therefore remain open during the last one-sixth of the outward stroke and the first one-sixth of the return. At this moment the air and gas

are transferred from the pumps through a valve and a series of perforated plates into the cylinder. During the return stroke, after the exhaust ports are closed, the mixture is compressed until the end of the stroke is reached, when ignition takes place. The piston is driven forward, and as soon as the exhaust ports are again uncovered the burnt gases escape as before. With this arrangement there is a possible danger that the explosive charge may escape at the open exhaust ports unless certain precautions are taken. In this arrangement the difficulty has been overcome by so disposing the pumps that they act successively and in such a way that the burnt gases are first expelled by a blast of atmospheric air, and that the charge is only admitted when the exhaust ports have

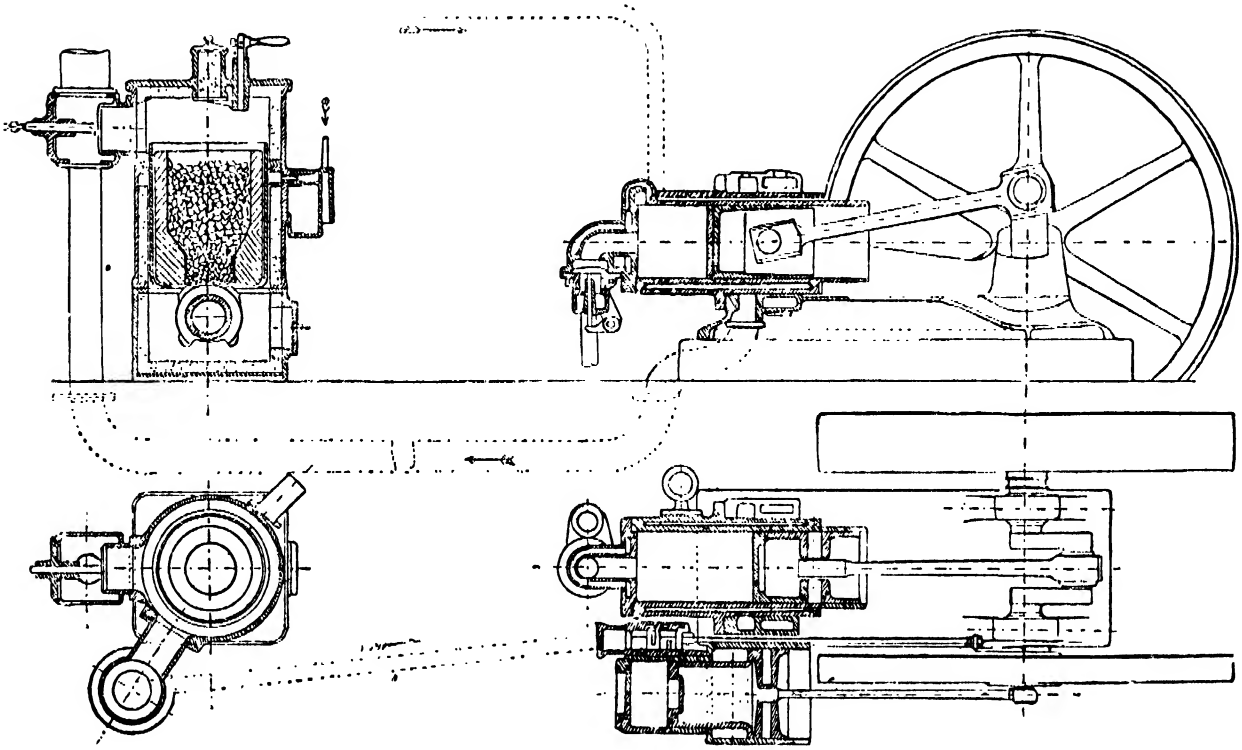


Fig. 401. Benier Suction-Gas Producer and Engine: Sectional Elevation and Plan

been covered by the piston. One driving stroke is obtained for each revolution of the crank shaft, and the pump draws the necessary gas from the producer as required and forces it into the cylinder. As the gas is withdrawn at each working stroke from the producer a new supply of air and steam is sucked in to replace it, so that the action of the plant becomes automatic, and the evolution of the gas varies with the demands of the engine.

Crossley Suction-Gas Plant. Fig. 402 shows the external appearance of the Crossley arrangement, which comprises the generator at the left and the washing cylinder or scrubber between the engine and the generator. No gasometer is required in plants of this description, as the gas is generated at each suction stroke of the piston. At the extreme left is shown the hand fan, which is used for starting the producer and for increasing the strength of the fire after a more prolonged stoppage. Anthracite is

most frequently used in the furnace, but bituminous fuels may also be burned with good results and freedom from clinkering.

Loomis Producer.—By means of a special ejector the air is sucked through the whole thickness of the fuel contained in a portion of the generator. The producer furnace, which is lined throughout with refractory material, has the usual charging arrangements at the top, and at the bottom a conical base takes the place of the customary grate bars. After its decomposition in contact with the incandescent fuel through which it is sucked, the air traverses a water-cooled spiral, in which it gives up its heat. In this way sufficient steam is generated for the supply of the ejector, which, as already stated, aspirates the air through the furnace. The air supply is then

Fig. 402.—Crossley Suction-Gas Plant

admitted to the main generator, where, in presence of the steam, hydrogen and carbonic oxide gases are evolved. Water gas or air gas, or a mixture of both, may be generated as required, and it has been found by experience that the plant may be run continuously without a stoppage or loss of efficiency for two years.

Wilson Producer.—Unlike the Loomis plant just described, the height of the generator chamber is greater than the width, an arrangement which permits of the use of small and dusty qualities of fuel. Observation holes are provided at a suitable level, through which fusion of the mass and any obstruction of the fire may be detected and remedied. Air is forced at a very small pressure, not exceeding 1 in. of water, into the incandescent mass by means of a steam injector, and the fire is carried upon rotating spiral bars, which dip on the lower side into cooling water. Any ash or clinker that may become fused to the bars is at once detached, whenever the part dips into the cold water, and falls into the ash pan. The heat of the waste gases from the engine is economically utilized in heating the air supply to the generator.

Dowson Suction Plant.—The Dowson plant, figs. 403 and 404, differs only in details from the Crossley plant already described, and it comprises the same essential parts. With an engine suitably adjusted the consumption of anthracite peas in the producer is guaranteed by the makers not to exceed 1 lb. per b.h.p. hour under full load, and the consumption of small coke of good quality is about $1\frac{1}{4}$ lb. per b.h.p.

Longsden Producer.—It has already been stated that the water gas generated in the plants described is largely used for illuminating purposes, and that in many American towns special plant is laid down for the purpose. To the use of water gas for public services there is, however, the very serious objection that water gas contains a large proportion of carbonic oxide, which is a poison of the most serious nature, even in minute quantities, and one that does not betray its presence by any odour. Many serious accidents have resulted from very small leakages from the pipe connections, and the danger is one that must be most carefully guarded against. As no cheap method of dissolving the gas is known, Mr. Longsden has resorted to the alternative system of preventing the production of the carbonic oxide, by the addition of soda to the fuel in the generator. Analysis of the gas produced by the reaction is as follows:—

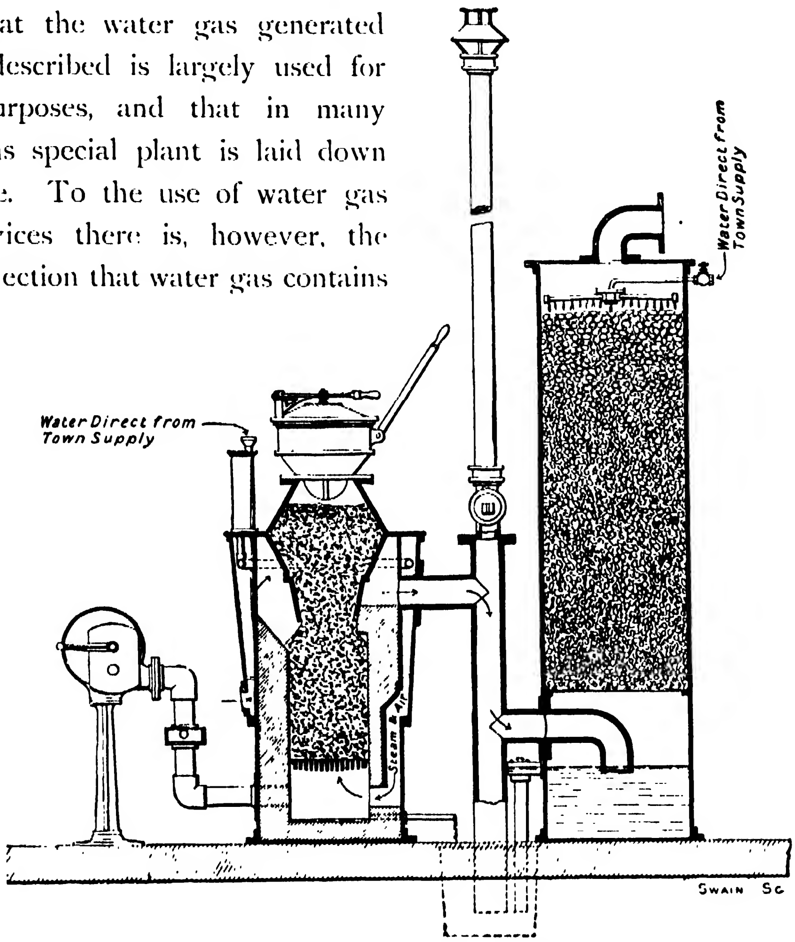


Fig. 403.—Sectional View of Dowson Suction Plant

Hydrogen	62.2 volumes
Carbonic acid	26.4 ,,
Carbonic oxide	1.2 ,,
Various hydrocarbons	2.2 ,,
Nitrogen	6.5 ,,
Oxygen	1.5 ,,
	100.0 volumes.

This gas, which is very rich, may be freed from its carbonic acid by passing it over the surface of chalk, and so made suitable for use in gas engines.

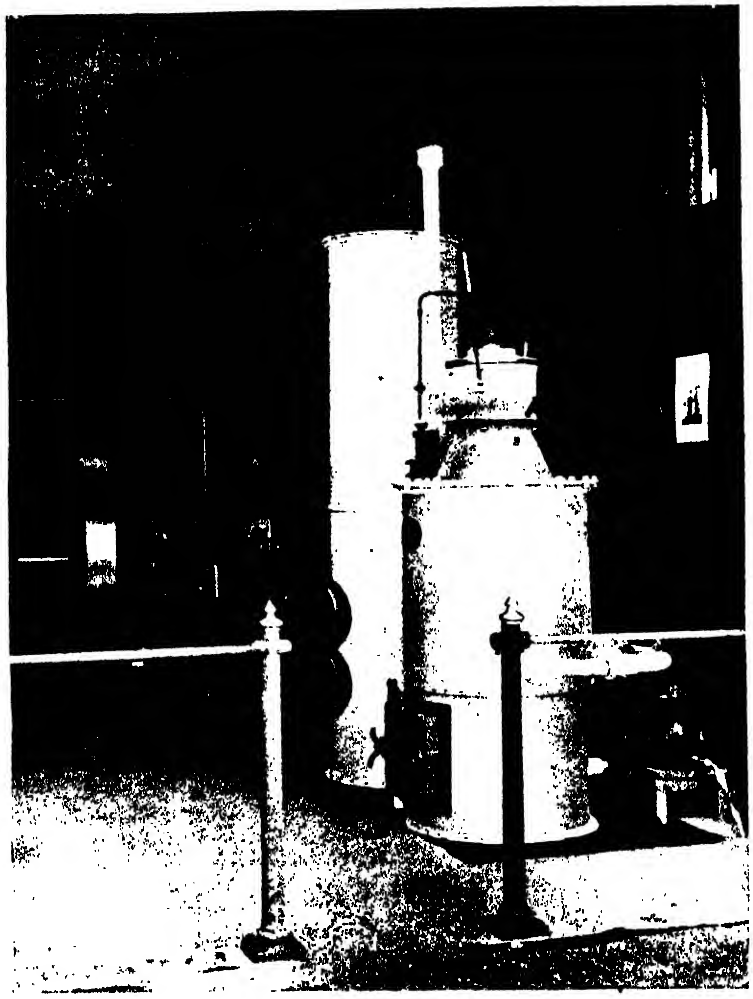


Fig. 404.—Dowson Suction Plant serving Gas Engine

MANAGEMENT AND UPKEEP OF INTERNAL-COMBUSTION ENGINES

Erection.- The following suggestions for the erection of oil and gas engines are taken from the *Traité théorique et pratique des moteurs à gaz et à petrol*, by M. Witz.

Gas engines are generally fitted upon a bed plate, which in the case of engines of more than 4 h.p. should be fixed upon a massive foundation of cement or brick, in order, as far as possible, to reduce vibration. Around the engine a clear space should be provided to give easy access to the parts when cleaning and repairing, or when starting by hand. On the nearest or most suitable wall should be arranged the gas and water cocks and the anti-pulsation gas bag, which should have a capacity of at least twenty-five times the volume of gas drawn into the cylinder at each working stroke. When these ample dimensions are adopted, all danger of a serious fall of pressure in the piping is avoided, and other intermediate regulating devices may be dispensed with. It is essential that

the bag should be arranged vertically, and that the indiarubber sides should remain unstretched. The tightness of the sides may be readily adjusted to give the best results by manœuvring the gas cock to suit the normal demand.

Water jackets are generally fitted to engines of 2 to 3 h.p. and upwards. When a supply of water under pressure is available it only remains to connect a branch from the water main to the jacket inlet by means of a pipe the diameter of which depends on the supply pressure. Unless other use is made of the hot water the circulation through the jacket should be so adjusted that the temperature of the water at the outlet is at least 60° C., and it is advantageous to go as far as 80° C., in which case, however, it is necessary to lubricate the cylinder with specially good oil. A thermometer at the jacket exit is useful for recording the temperature, which may then be maintained at a uniform level by means of the inlet cock.

When a jacket water supply is scarce or costly it is necessary to install coolers, so that the same water may be repeatedly used. It is frequently sufficient to place a reservoir above the level of the engine, with the bottom in communication with the lowest part of the jacket and the top with the upper portion of the jacket, so that the differences of the densities of the hot and the cold water will ensure a circulation through the system. About 100 gal. of water should be provided for each horse-power of the engine, unless special cooling arrangements having a large cooling surface are adopted, as in the Koerting system, in which only 44 gal. of cooling water per horse-power are required.

Starting and Stopping.—The engine should always be started with care and deliberation. First the gas cocks to the burner or the ignition tube should be opened, and in the latter case the tube brought to a red heat. When the ignition is effected by means of a battery, the zinc of the battery should be lowered into the electrolyte, and the trembler put into vibration by turning the commutator. All working parts should be lubricated, and the oil cups replenished where necessary, and then the fly-wheel of the engine may be rotated by hand or otherwise until the first charge is drawn in, compressed, and finally ignited. If the engine is not provided with a self-starting gear, care should be taken that the gas-supply valve is only partially opened, until the speed of the engine has reached the normal, when the load may be put upon it by shifting the belt, and the speed adjusted by opening the gas cock.

If the engine refuses to start, the gas valve should be inspected to see that it is not too open; and if the fault does not lie there, the ignition should then be examined. Occasionally the fault is due to leakage at the exhaust valve, which prevents the mixture being compressed to the required extent. This defect may be detected by rotating the flywheel backwards, and then noting if the compression produced in the cylinder is sufficient to move the piston forward again.

Excessive lubrication of the cylinder and working parts is objectionable, as a very small quantity of oil is really required for efficient lubrication, and to prevent waste of oil all parts of the mechanism should be kept in a clean and bright condition.

It is not essential that the gas-engine attendant should be a specially skilled mechanic. All that is necessary to ensure regular running, and to preserve the condition of the engine, is reasonable care and vigilance on the part of the attendant, and the

power of detecting the first appearance of defects. Under these conditions the durability of the gas engine may be considered as equal to that of the steam engine, although the cost of upkeep is greater.

Before proceeding to stop the engine, the self-starting gear, where such is fitted, should be brought into operation, so as to ensure its action when it is required to restart the engine, and then the gas supply should be cut off. Until this is done the ignition flame or spark should not be stopped or the jacket-water supply cut off. If the stoppage is to last for any considerable time, the piston should be stopped in the extreme outer position, so as to prevent dirt and grit from settling upon the inside surface of the cylinder.

Very little attention is required to ensure continuous and regular running once the gas and water valves have been adjusted. All that is required is occasional supervision to ensure that the oil supply does not fail, or that the temperature of the jacket water does not unduly rise, in which case there would be serious danger of the piston seizing in the cylinder. Every month, or even more frequently, the cylinder and valves should be cleared of all carbonaceous deposits, and every six months the valves should be reground and carefully reset. If regularly attended to in this way the engine will continue to work at its full power, and the time and trouble will be amply repaid by the satisfactory action of the engine at all times.

Care of Oil Engines. These engines require not only the same care as the gas engine, but also additional supervision on account of the extra gear involved in the atomizing and carburation of the oil. Carbonaceous deposits form sooner or later in the carburettor, as a result of the pulverization and combustion of the oil, and these parts require to be examined at regular intervals of at least a week, and to be freed every month of all accumulations of carbon, oil, and soot. Some attention must also be given to the vaporizer lamp from time to time.

Ignition of the Explosive Mixture. There are several methods of igniting the charge in the cylinder, each of which may be said to have certain advantages and disadvantages. Ignition by means of an iron or porcelain tube heated to redness is the simplest and most certain of the methods. The exposed flame and slide system is somewhat more complicated, and the use of a magneto driven from the engine itself, while requiring less attention, is less convenient when starting. Batteries are generally used for spirit vapour and oil engines, but their upkeep is troublesome. From the point of view of economy it would be difficult to say which system is the best, as all give satisfactory results; for while the ignition flame and tube consume gas the battery consumes zinc. When a battery is used it should be amply powerful, and the strength of the current should be constant. A suitable form is the ordinary zinc and carbon bichromate battery, which does not readily polarize when in continual use. The induction coil used for the ignition is really a transformer, which converts the comparatively low-pressure battery current into a high-pressure current in the sparking-plug circuit. Every time the battery circuit through the primary coil is closed or opened by the vibration of the trembler, a momentary current is induced in the winding of the secondary coil, and the pressure of this induced current depends upon the relative number of turns in the two windings. It is only at the moment of making or breaking the primary circuit

that the momentary current is induced in the separate secondary circuit. This latter circuit ends in the sparking plug, which is enclosed in the ignition chamber. Through the end of the porcelain plug the two terminal wires project, and are thus separated by an air gap, across which the sparks jump each time the primary circuit is made or interrupted. A bulky torrent of sparks gives more certain and better results than a thin intense one, so that it is not advisable to use too high a secondary-coil pressure. Hard deposits of carbon form readily between the sparking points, and it is advisable to frequently examine them, and, if necessary, to clean them once each week of running.

SECTION VII

THE MOTOR CAR

THE MOTOR CAR

If, in the early days of mechanical locomotion on the public highways, conditions had been more favourable, the development of the motor-car industry would undoubtedly have been greatly advanced; but for nearly half a century all progress was blocked, chiefly by the opposition of the large coach proprietors, who controlled practically the whole internal traffic of this country. For many years thereafter further experiments were abandoned, and with the advent of railroads and the locomotive the first stage in the history of steam carriages was closed. Although intermittent attempts were made to revive the system of road locomotion, it was not until 1883 that the motor car industry of the present day originated in any really commercial sense. Count Albert de Dion (now Marquis), while promenading one of the Paris Boulevards, where novel mechanical toys were exhibited by street hawkers, was impressed with the idea of replacing the ingenious clockwork mechanism of a small toy carriage by some more suitable form of motor. For the mechanical development of his ideas the count entered into partnership with the inventor of the toy carriage, and as a result of their joint efforts the small steam car illustrated in fig. 405 was constructed and run, with considerable success, in 1883. Although the results were very promising, and indicated what might be expected in the future, it was evident that some new type of boiler would require to be devised to meet the very special requirements of a steam car namely, rapidity of action, safety, and power. The system of flash boilers, applied with so much success by De Dion, Léon Serpollet, and by later makers of steam cars, consists in generating sufficient steam for each stroke of the engine as it is required, and in having at no time any considerable quantity of water in the boiler. Sufficient water for the production of a cylinderful of steam is forced by a pump through the thin water space of the boiler tubes, which have very thick walls, capable of retaining a large quantity of heat, and of withstanding with safety any pressure that may arise. At each stroke of the engine a new supply of water is forced in by the pump, so that only the quantity of steam required from moment to moment is generated. In the boilers of modern steam cars where oil fuel is used, as is customarily so, the supply of oil to the heating burner varies with the action of the engine, and is almost entirely cut off when the engine is stopped. This type of boiler will be again referred to

when describing in detail the principal makes of steam cars. Subsequent developments of the steam car only helped to demonstrate, instead of to overcome, the objections to the system which involved the carriage of not only water, but also of a supply of coke for the furnace, as at that time the use of oil fuel was practically unknown. Attention was accordingly directed, by Gottlieb Daimler and Carl Benz independently, to the development of internal-combustion engines, and soon the steam engine, so far as its use in cars was concerned, was entirely superseded by the petrol motor.

At the present time the great majority of motor cars are provided with engines of the internal-combustion type, burning petrol vapour, and only a relatively small

Fig. 405.—First Steam Motor Car (1883), by Marquis de Dion

proportion of steam or electric cars is manufactured. This is not due wholly to the superiority of the petrol system over either steam or electricity in all respects, but rather to the failure, of the latter in particular, to satisfy every requirement, and also to the greater amount of attention that has been concentrated upon the development of the petrol car by a host of skilled designers. If in the early days oil fuel could have been substituted for coke, as it is now, and if the same attention had been devoted to the development of the system, petrol and steam would probably now be more equally favoured by the public. Each of the three systems, petrol, steam, and electricity, has its advantages and disadvantages, and the suitability of any one for any particular case depends upon how many of the conditions are satisfied by it. The comparative advantages may be roughly summarized here, but it should be noted that what is an advantage under certain conditions may not be so under others. Where the variety

of types is so great it is not possible to make any rigid classification of general application.

Petrol Cars.

Advantages—

Great perfection of design, the result of much experimenting by the skilled manufacturers concerned in their development

Variety of types to choose from.

Small space required for the storage of the petrol, increased range, and the ease with which the store may now be replenished at any country town.

Disadvantages—

Inherent objections to the four-stroke cycle, with only one impulse per cylinder every two revolutions, and a high initial explosive pressure.

The high temperature of combustion necessitating the use of efficient water jackets and cooling and circulating arrangements, and involving the carriage of a store of cooling water.

Increased difficulty of lubricating the cylinder at the high temperature.

Occasional unpleasant exhaust.

Necessity for a gear box or other arrangement for varying the speed.

Steam Cars.

Advantages—

Two working strokes per cylinder, if desired, for each revolution.

Flexibility of the steam engine as regards power.

Reduced working temperature and freedom from excessive vibration.

No water jackets or cooling arrangements.

Simplicity and ease of control, especially when starting.

Exhaust, if sometimes visible, is at least inodorous.

Disadvantages—

Limited choice of types.

The use of a steam boiler and oil burner, however compact and simple.

Electric Cars

Advantages—

Directness and simplicity.

Ease of speed control.

Absence of objectionable speed-gear wheels.

Freedom from vibration, and quietness of the running.

Cleanness.

Flexibility of the system as regards the power developed.

Disadvantages—

- The use of heavy and expensive accumulators, both as regards first cost and upkeep.
- Time required for recharging the batteries, unless a second set of accumulators is used.
- Limited number of charging stations.
- Low capacity of the accumulator, giving for one charge of the cells a range of from 20 to 40 miles.
- Initial cost and running charges.

It is not possible to give any rigid comparison of the three systems of petrol, steam, and electric cars, or to state the relative importance of their respective merits and demerits. Much skilled attention has been concentrated upon the problems of the petrol motor, particularly in its application to motor cars, by an ever-increasing body of experienced manufacturers throughout the country, and as a result the system as a whole has been brought to a state of great perfection. It is now possible, in even the villages of the country, to replenish the store of petrol or to carry out small repairs when required. As the number of petrol cars increases the experience of mechanics continues to grow, and there is little difficulty now in obtaining in any small town some skilled help in the event of a breakdown. Steam cars, on the other hand, do not so frequently come under the notice of these local engineers, and, as a result, there is not so general a knowledge of their ailments. The present almost universal adoption of the petrol system is frequently a determining factor in the choice of a car, apart from any possible superiority of one system over the other.

Where cost of running is of secondary importance, as in the case of the town practice of a medical doctor, or for the service of theatres and other similar purposes, the electric motor car is greatly favoured on account of its very silent running and general suitability for such work. For touring purposes, however, the electric car is quite unsuitable, on account of its excessive weight and small radius of action, and for the other reasons referred to above. Small private installations, comprising a gas engine and dynamo, have been frequently installed by users of these cars, for the charging of their cells when a public supply of current was not available.

These three systems, which are the only ones in practical use, will be now separately considered in some detail.

PETROL MOTOR CARS

Crude petroleum, from which is derived the commercial petrol consumed in motor cars, is obtained largely from natural sources in Russia and America, and to a smaller extent from Roumania and other neighbouring districts. In Scotland a certain quantity is obtained by the distillation of oil-bearing shales, but the amount is inconsiderable. In its natural state the petroleum consists of a mixture of hydrocarbon oils, which

change from the liquid to the gaseous state at very different temperatures. Fractional distillation, which consists in condensing the oils given off, at different temperatures, is therefore resorted to, in order to separate these various oils.

Each oil is commercially specified by its specific gravity or density and closed and open flash points; the latter being the temperature at which, under atmospheric pressure, the oil commences to give off inflammable vapours.

Benzene, naphtha, and gasolene are vaporized at temperatures below 73° F., and owing to their inflammability it is necessary, under the Board of Trade regulations, to adopt certain precautions when handling them; and for insurance purposes it is necessary to notify the companies involved.

Kerosene and illuminating oils are next in order of distillation, at temperatures of from 77° to 122° F.; and, as these oils can be handled with safety, fewer restrictions upon their use are imposed by the Government. At temperatures up to 425° F. the lubricating oils are vaporized and separated, and thereafter the paraffin waxes are recovered. The residue consists of the dense oils used as liquid fuel in furnaces.

It is not possible to burn the crude petroleums in motor engines, owing to the very high temperatures required for their complete combustion; and only the lighter classes of the gasolene oils already referred to, having specific gravities of from 0.68 to 0.72, are generally used under the name of petrol or motor spirit. These oils, being of the most inflammable description, come under the Government regulations, and must be handled with the greatest care.

Arrangement of the Car Elements. Although it would be more systematic to describe the various organs of the motor car in the order in which they deal with the working substance, and in which the heat energy is converted into mechanical energy and then applied at the road surface, the less regular course will be adopted of describing the principal elements first, as some knowledge of their working and arrangement will make the actions of the minor portions clearer.

It is first necessary to consider the car as consisting of—

1. The Chassis.
2. The Body.

The chassis comprises all the mechanical parts, together with the frame upon which they are carried, and its design and construction are the concern of the particular maker rather than the buyer; whereas the body, which includes the carriage work, must be varied to suit the taste of the purchaser, although there are certain recognized forms which are generally adhered to.

Fig. 406 is an elevation, and fig. 407 a plan of an Albion chassis, the parts of which have been numbered and correspondingly indexed for the purpose of description; and fig. 408 shows the completed car.

Petrol is stored in the supply tank 34, carried on the dash-board 33, and passes to the float feed chamber of the carburettor 15, where it is vaporized and mixed with air before its entrance into the working cylinder. A silencer is attached to the air inlet of the carburettor to suppress the noise of the suction. After its combustion in

the working cylinders of the motor, the waste gaseous products are exhausted through the exhaust valves at 11, and through pipe connections, not shown in the figures, to the silencer, which reduces the explosive report of the gases as they escape to the

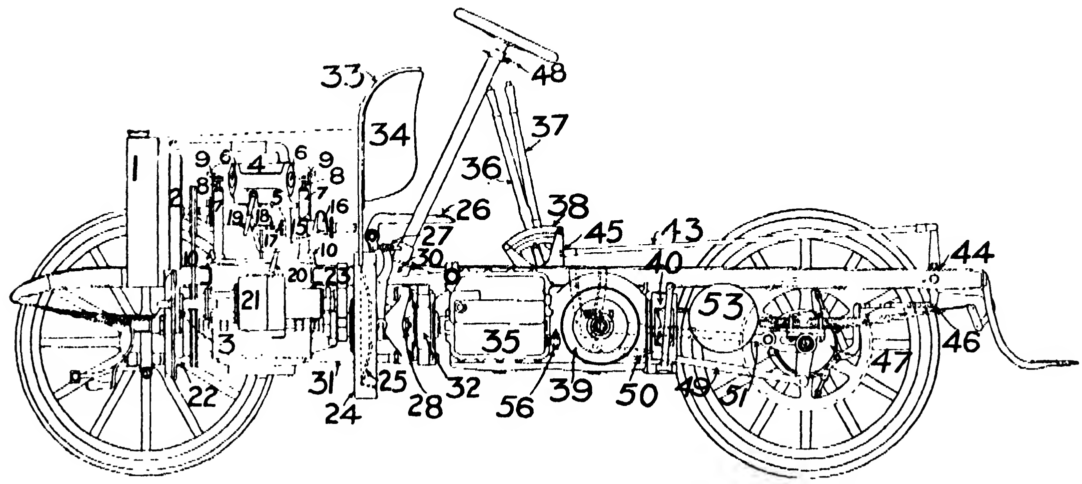


Fig. 406. Arrangement of Albion Chassis: Elevation

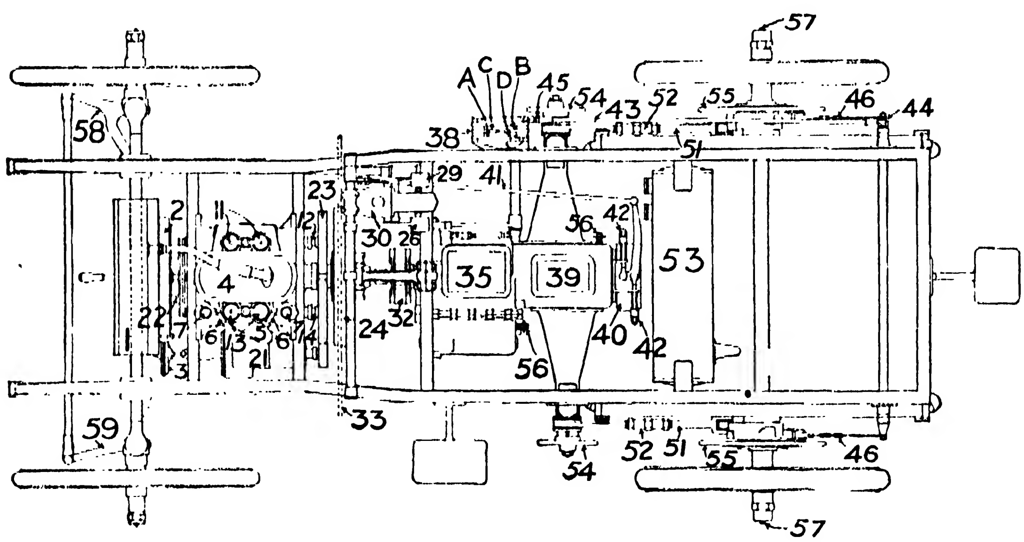


Fig. 407. Arrangement of Albion Chassis: Plan

1. Cooler
2. Fan.
3. Pump.
4. Water jacket cover.
5. Suction port.
6. Ignition ports.
7. Ignition columns.
8. Ignition rods
9. Ignition hammer
10. Ignition advance gear.
11. Exhaust valve covers.
12. Exhaust-cam shaft.
13. Inlet-valve covers.
14. Suction and ignition cam shaft.
15. Carburettor
16. Auxiliary air inlet.
17. Throttle valve
18. Adjustment for throttle valve.
19. Governor control lever.
20. Governor wyper.
21. Governor box
22. Magneto.
23. Cam shaft and governor gear wheels.
24. Flywheel.
25. Clutch
26. Clutch pedals.
27. Adjusting nut for clutch pedals.
28. Nut for adjusting clutch spring.
29. Brake pedal.
30. Steering gear.
31. Steering connection rod.
32. Spring drive.
33. Dash board.
34. Petrol tank.
35. Gear box.
36. Change speed lever.
37. Hand-brake lever.
38. Change-speed bracket. A, 1st speed; B, 2nd speed. C, 3rd ,, D, Reverse.
39. Differential gear box.
40. Foot brake.
41. Foot-brake rod.
42. Foot-brake adjusting nut.
43. Hand-brake rod.
44. Hand-brake compensating gear.
45. Hand-brake adjusting nut.
46. Hand-brake adjustable links
47. Hand brake.
48. Governor lever.
49. Brake stay rod.
50. Brake stay rod adjusting nut
51. Radius rods.
52. Radius-rods adjusting nut.
53. Silencer.
54. Chain pinions.
55. Chain wheels.
56. Oil overflow cocks.
57. Hub-oiling screws.
58. Off steering arm.
59. Near steering arm.

air. Ignition of the mixture in the cylinders is effected electrically by the sparks produced by the magneto 22. To prevent the cylinder temperature from becoming excessive, a supply of water, cooled in the radiator 1, is circulated by a centrifugal

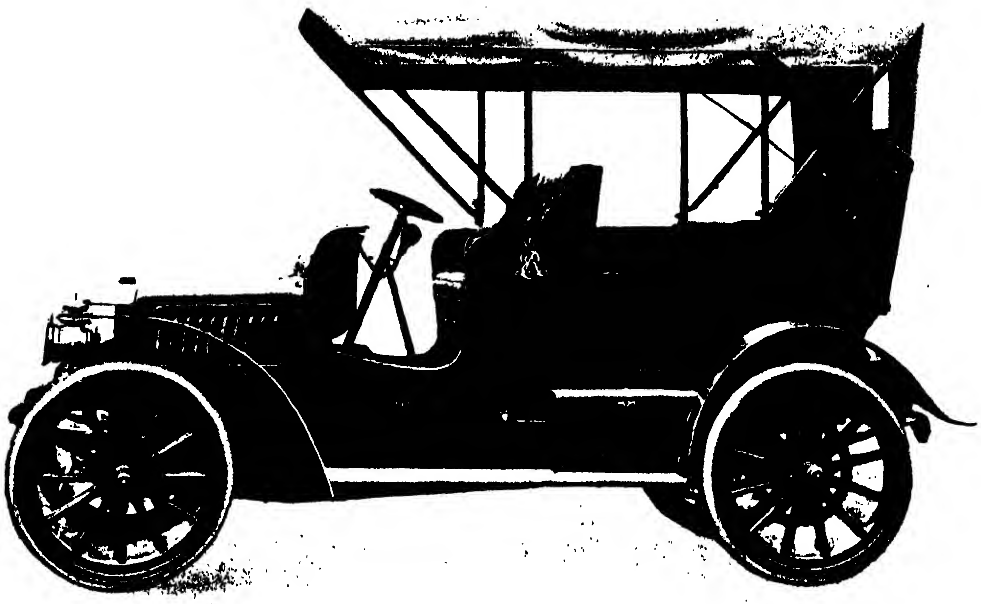


Fig. 498. Albion 16-H.P. Car: Side-entrance Tonneau

pump 3 through the jackets around the cylinders, and other parts subjected to the high temperature of the combustion. During the working of the engine the fan 2 draws cold air through the radiator and causes it to circulate around the engine.

These parts, as far as the clutch 25 on the engine shaft, may be considered as the motor which converts the heat energy of the petrol into mechanical energy, while the succeeding parts, which serve for the transmission of the driving forces to the wheels, are included under the general term transmission. The rotational motion of the engine shaft is transmitted through the friction clutch 25, and the spring drive 32, which takes up momentary shocks to the speed-gear box 35, and the differential-gear box 39, from which the chain pinions are driven. The driving force generated in the engine is thus finally transmitted, through chains in this particular instance, to the driving wheels of the car. Within convenient reach of the driver is placed a hand lever for controlling the speed gears in the box 35, and the pedal 26 enables the clutch to be disengaged, thus disconnecting the engine and the transmission.

Two sets of brake gear are generally supplied, one on the transmission shaft at 40, operated by the pedal 29, and one on each of the driving wheels, controlled together by the hand lever 37.

Steering is effected by suitably directing the front wheels, which are connected through the arms 58 and 59, and through the steering gear 30, with the steering wheel placed in front of the driver.

Reference will be made later to the various systems of controlling the mixture, supplying the petrol, and lubricating the working parts, as these vary greatly in the cars of different makers.

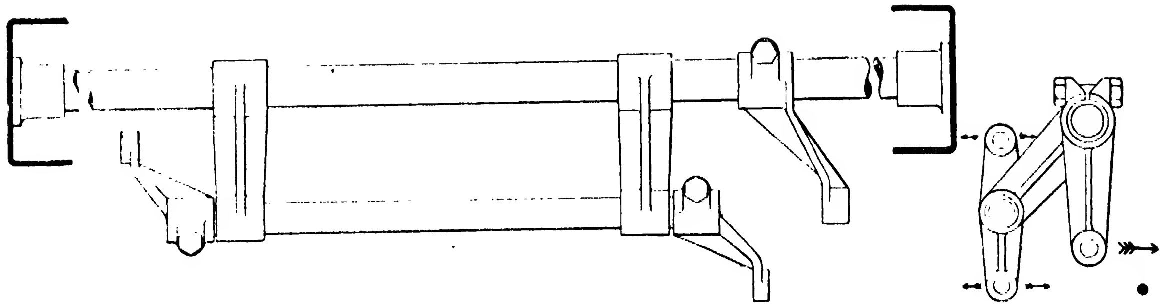


Fig. 409. Speedwell Chassis: Section of Frame

Frames. When car powers were not great, as in the earlier days of the industry, the frames were built up of ash or other suitable woods, reinforced with metal flitches; but in order to satisfactorily withstand the heavy stresses that come upon the powerful cars of the present time, and to reduce the weight to a minimum without unduly affecting

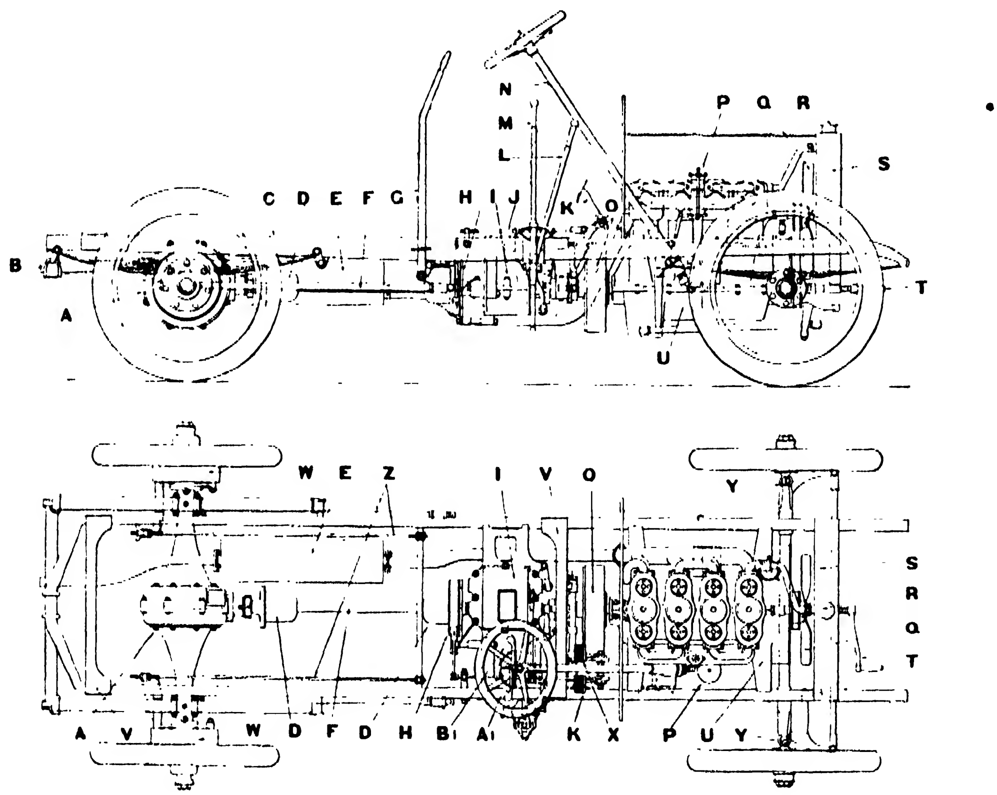


Fig. 410.—14-16-H.P. Argyll Chassis

A. Differential-gear casing.
B. Spring shackles.
C. Frame longitudinal runner.
D. Universal-joint casing.
E. Silencer.
F. Propeller shaft.
G. Hand-brake lever.
H. Foot-brake drum and sprag.
I. Gear box.
J. Foot-brake rod.
K. Foot-brake pedal.
L. Reverse-speed lever.
M. Change-speed lever.
N. Steering column.
O. Flywheel and clutch.
P. Carburettor.
Q. Fan.
R. Water filler.
S. Radiator.
T. Starting handle.
U. Engine-crank case.
V. Frame crossbar.
W. Brake drum.
X. Clutch pedal.
Y. Steering pivots.
Z. Back-brake pull rod.
A_1. Ignition-control lever.
B_1. Throttle-control lever.

the strength, the frames, excepting in the case of certain types of small cars, are made of pressed steel of channel section, arranged horizontally, as in fig. 409, or vertically, as in the Argyll Chassis, shown in fig. 410, where the inverted ∩ section is adopted. From an examintion of this chassis it will be seen that sufficient side rigidity to

withstand the severe stresses that arise when such heavy cars require to turn sharply, with a considerable load, is obtained by bracing the frames together with cross bars V, while additional rigidity is given to it by the cross brackets carrying the engine U and the gear-box I. Tubular steel cross bars are also frequently used in other types of frames for the same purpose.

It will be seen also, from the side view of the illustration, fig. 410, that the frame is deepest at the middle, where the most severe bending stresses occur, and that the ends are curved in order to give ample room for the movement of the springs. In the Albion Chassis, fig. 408, the forward end is narrowed to give more room, or, as it is called, Lock, for the turning of the front steering wheels. This is particularly necessary in cars of long wheel base, where the wheels require to swing through a considerable angle in order to turn the car in a reasonably small length.

Some importance attaches to the position of the frame above the ground. If placed too high it interferes with the body of the car, and makes the arrangement of side entrances more difficult; while, on the other hand, if placed low down, the car when running tends to raise dust, unless particular care is taken to dispose the engine and mechanism as high as possible above the ground.

Springs.—Semi-elliptic laminated springs are generally arranged longitudinally, as shown in figs. 406 and 410, to absorb the more severe shocks, as the tyres alone cannot deal with any but small unevennesses of the road. The springs are attached by links to the dumb irons, secured to the extreme ends of the side frames, and at the inner ends by similar links to brackets, or directly to the frame. A transverse spring is placed in several types of cars at the rear of the frame, but never at the front, as dangerous side rolling may be thereby introduced. Rubber buffers and checks of various kinds are provided where necessary, to limit the extreme motion of the springs.

Wheels.—Not only have the wheels to carry the load and transmit the drive, but they are also subjected frequently to very severe side stresses, when, for example, a side slip takes place, or the wheel comes into contact with the kerb of the road. They require, therefore, to be constructed to withstand strong forces applied both vertically and horizontally. Wooden wheels are most generally adopted at the present time, although there are advocates of the wire-spoked wheel, which at one time was more generally favoured. A special form of artillery wheel, as fitted to Argyll cars, is illustrated in fig. 411. The spokes C, of seasoned oak, are tenoned into ash felloes B, which are bound together by the steel tyre D, and the inner ends of the spokes are socketed between the hub plates A, which are so arranged that any slackness of the spokes, as, for example, in long-continued dry weather, may be taken up. The spokes are inclined to the vertical, alternately in opposite directions, to withstand side forces, and this arrangement, together with the insertion of felt packing between the spoke ends, permits of the wheel being tightened by bringing the hub flanges closer together. In many cases the simple type of artillery wheel, with metal hub and with the spokes inclined in one direction only, is adopted. Wire wheels are not so frequently adopted, owing largely to the difficulty of keeping them clean, and possibly on account of appearance. They are lighter and more readily repaired than wooden wheels, and when the spokes are

sufficiently staggered, and are arranged tangentially, they are quite able to carry the load and to withstand severe side stresses.

Tyres. Solid and pneumatic tyres have each their advocates, but it is not possible to make any rigid comparison, as the relative importance of their merits depends upon the conditions to be satisfied. Where smooth running and freedom from all vibration at high speeds is essential, pneumatic tyres are generally fitted; but for slow-running cars, solid tyres are often used with satisfactory results, especially when the springs are made specially resilient. As already stated, the springs absorb the heavier shocks, while

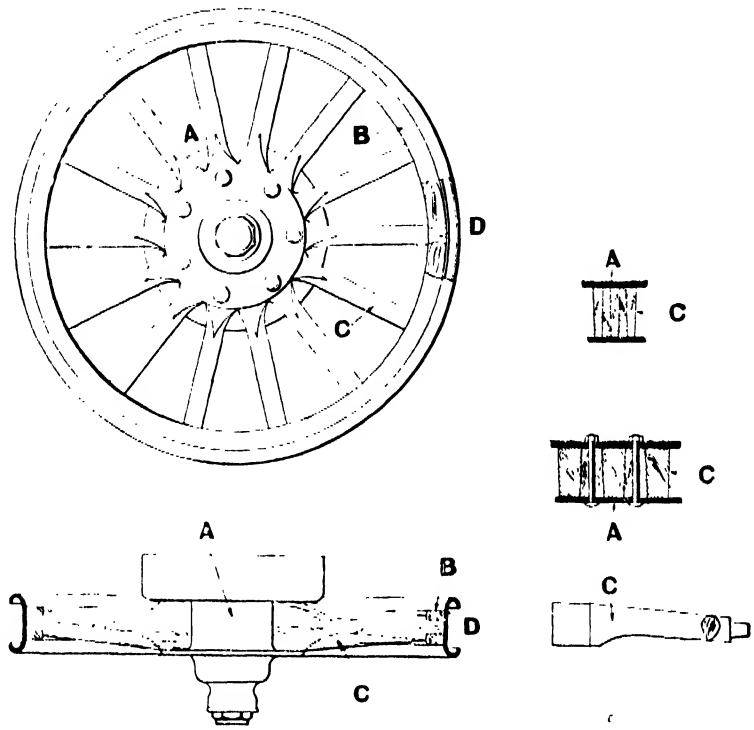


Fig. 411. Staggered spoke Road Wheel (Argyll Motors Limited)

A, Iron hub; B, Wheel felloes; C, Spokes, right and left hand; D, Steel tyre of wheel

the rubber tyres, whether solid or pneumatic, accommodate themselves in different degrees to small inequalities of the roadway, by filling up small hollows and including projections. The solid tyre has the advantage of freedom from puncturing or the other ailments of the pneumatic tyre, but experience has shown the advisability of fitting pneumatic tyres to at least the steering wheels, with either pneumatic or solid tyres on the driving wheels according to the circumstances.

In certain greasy conditions of the road surface, rubber-tyred wheels are very liable to side slipping, however carefully the car may be run. To remedy this serious danger the tyre faces are grooved or armoured with metal projections, which improve the grip of the wheels. There are on the market various removable non-skid devices of studded bands or chains, which meet the difficulty in a satisfactory way.

The Engine.—Fig. 412 illustrates diagrammatically the whole engine system, from the petrol-supply tank to the silencer on the exhaust pipe. At each suction stroke

of the piston, that is, as it moves outwards, petrol is sucked from the supply tank through the float feed chamber and through the spray nozzle of the carburettor. Air is at the same time sucked in through the air inlet, and in its passage across the nozzle it breaks up or atomizes the stream of petrol, and mixes intimately with it to form a gaseous mixture, the richness of which may be regulated by suitably controlling the sizes of the oil and air inlets. The explosive mixture enters the cylinder through the inlet, or, as it is sometimes called, induction valve, which is held open during the stroke, either mechanically or by the difference of pressure due to the suction. As soon as the piston commences the return stroke the inlet valve is released, and closes under the action of a spring, and, since the exhaust valve still remains closed, the mixture in the cylinder becomes highly compressed into the small space at the end of the cylinder, and is then

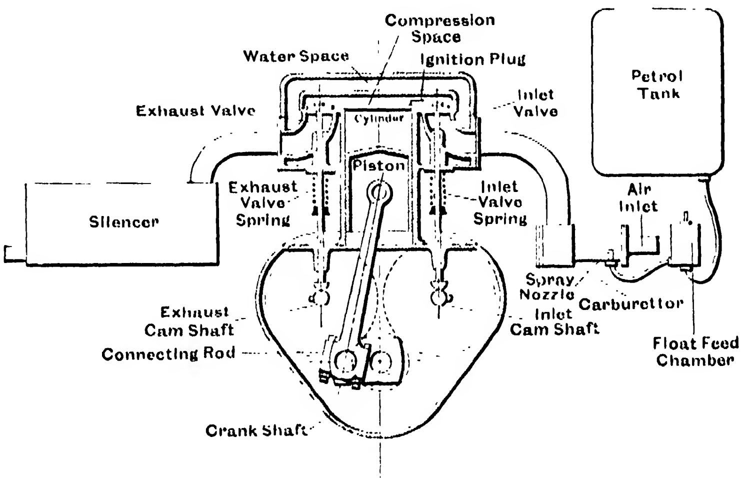


Fig. 412.—Diagrammatic Arrangement of the Engine System

ready for ignition. This is effected electrically by passing a spark between the points of the ignition plug, shown projecting into the valve chamber; but, as the exact moment of igniting the mixture after the piston has reached the end of the inward stroke is of some importance, means are generally provided for advancing or retarding the ignition relatively to the position of the piston. When the mixture is ignited, the oil vapour burns with great rapidity with the evolution of heat, and is converted into gas at a high temperature and pressure, which expands and drives the piston outward again. At the end of this working stroke the exhaust valve is automatically opened, while the inlet valve still remains closed, and the waste gases are exhausted throughout the return stroke into the silencer, and thence to the atmosphere. If no silencer were fitted to the exhaust pipe, the sudden reduction of the pressure at the exit would result in a loud report at each discharge. But by expanding the exhaust gases into the silencer the pressure is more gradually reduced to the pressure of the atmosphere, and all objectionable reports are avoided. Care must be taken to make the silencer sufficiently ample to prevent any serious increase of back pressure. At the end of the exhaust the piston recommences the cycle by drawing in a new charge of the explosive mixture.

These four stages, which constitute what is called the Otto cycle, may be summarized as follows:—

1. Out stroke. Suction. The mixture is drawn into the cylinder.
2. Return stroke. Compression. The charge is compressed.
3. Second outward stroke. Firing, and expansion under the piston throughout the working stroke.
4. Return stroke. Exhaust of the waste gases. Sometimes called the Scavenging Stroke.
5. Stage 1 repeated, and so on throughout the new cycle.

It will be observed from the brief description given above that the inlet and exhaust valves are each opened once per cycle, that is, once for four strokes of the piston or two revolutions of the crank, and the valves must therefore be operated from a shaft so geared as to make one revolution while the crank shaft makes two. This shaft will be referred to as the half-speed or half-time shaft.

Motor-car engines are generally provided with from two to six or eight cylinders, according to the power required, as the development of the whole power in one cylinder would involve very heavy parts, besides increasing the balancing difficulties and giving irregular motion. Very small cars are sometimes fitted with single-cylinder engines similar to those fitted to motor cycles; and, as an example of the single-cylinder type, the De Dion Bouton 8-h.p. motor, illustrated in figs. 413, 414, 415, and 416, will be described in detail.

Fig. 413 shows the timing side of the motor, with the gear exposed and parts in section.

Fig. 414 is an external view of the completed engine.

Fig. 415 shows the compression-release gear, and fig. 416 is a section through the crank casing clearly indicating the lubrication arrangements.

In this particular design the whole of the gear is assembled on the side of the engine casing; the two valves are contained in one chest, and the valves and spindles are the same and therefore interchangeable. In the 8-h.p. engine the cylinder diameter is $3\frac{15}{16}$ in. (100 mm.) and the stroke $4\frac{3}{4}$ in. (120 mm.). Both valves, $1\frac{5}{8}$ in. diameter, are mechanically operated, and the lubrication is forced by an oil pump. The cylinder, 1, has a malleable cast-iron cap 2, which includes the water-outlet pipe 3. This outlet is elbow-shaped to permit of the valve-cover plugs 4 being removed. 5 is the inlet and 6 the outlet valve, which, as already stated, are interchangeable. Their operation will be explained later.

The crank case 7 is of aluminium cast in two pieces and assembled by ten bolts 8; one of which, 9, is utilized as an oil-distributing channel. Four supporting brackets, 10, are provided, so that the engine may be bolted directly to a frame or a bedplate. This arrangement protects the motor from external straining forces. All the timing gear is carried on the valve side of the casing and is covered by an aluminium plate 11.

Timing Gear.—The starting-side end of the axle, 12, carries a pinion, 13, which meshes with the pinion 14 on the hub of which the timing cam 15 is cut. This cam, which rotates at half the speed of the crank shaft, operates in turn the inlet and exhaust valves by means of two levers working on the axles 16 for the inlet and 17 for the

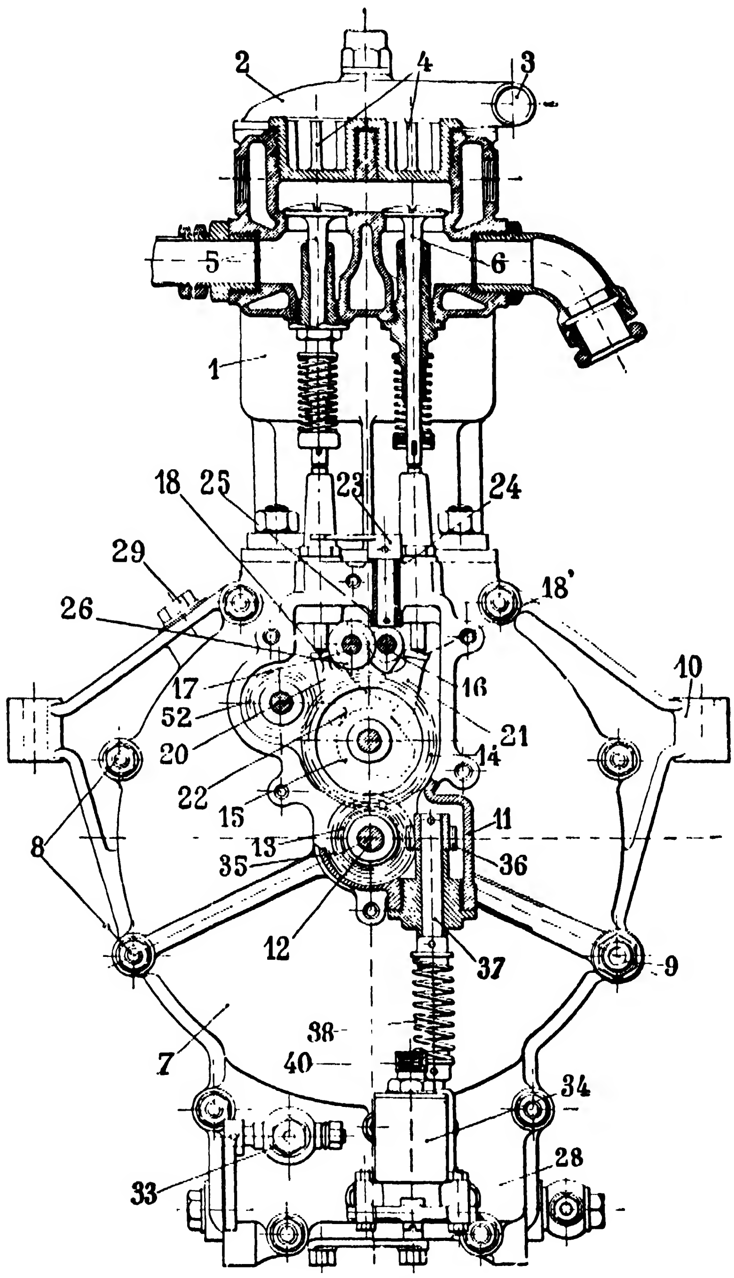


Fig. 413.—Side Elevation De Dion-Bouton Single-cylinder Engine

exhaust. Each of the levers, which cross one another as shown, has a flat face upon which the lifting rods of the respective valve spindles rest. By suitably arranging the levers 20 and 21, the suction and exhaust periods may be correctly adjusted. A compression release acting on the exhaust valve, as shown in fig. 415, is also provided. On the side of the cam, close up to the pinion 14, a small projection is formed, which engages when required with the exhaust lever and allows some of the gas to escape

during the compression stroke. When the outside lever 23, pinned on the shaft 24, is pulled, the inside lever 25 pushes against the collar 26 of the shaft 17, which by forcing outwards the lever 21 actuates the exhaust valve. Thus when the small projection 22 of the cam passes under the cylindrical part of the lever 21 the exhaust valve is raised, and when the outside lever 23 is released the spring 27 returns the inside lever 21 to its normal position.

Lubrication. At the bottom of the crank case is formed a reservoir 28, into which the oil admitted at 29 drains through the opening 30 and the gauze strainer 31 (fig. 416). This strainer is attached to the cover 32, and may be removed for cleaning. By means of the tap 33 the fulness of the reservoir may be tested. The oil pump is of the double-pinion type, which will be described later, and is driven by a worm, 35, fixed on the hub of the timing pinion 13. From the worm 35 is driven the helical pinion 36, on the shaft 37, which is coupled to the pump spindle through the spiral spring 38. Filtered oil is drawn

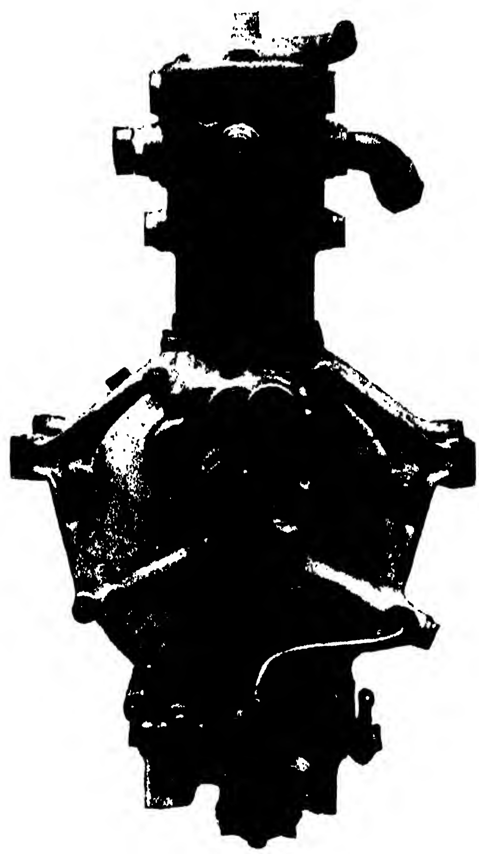


Fig. 414.—External View of De Dion Single-cylinder Engine

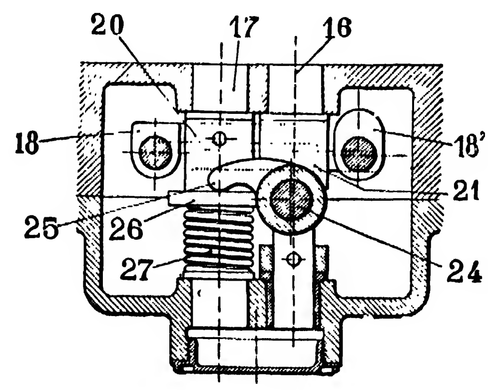


Fig. 415.—Section through Compression Release Gear

by the pump from the reservoir 28, through the connection 39, and forced out to the hollow bolt 9, through a pipe attached to the outlet 40, as indicated in the side view, fig. 413. The pressure, which is regulated by a spring-controlled valve, causes the oil to rise through the hole 41 to the main-shaft bearings, and thence to the crank-pin bush 43, through the oblique passage 44 and 45 in the shaft, crank web, and pin; but only once each revolution, when the aperture in the shaft comes opposite the opening of 41 in the bearing. To prevent the oil as it leaves the crank pin from being thrown, by the motion of the flywheel, up through the connecting-rod aperture 46 into the hot cylinder space, where it would burn and produce smoke at the exhaust, two splash plates, 47, are attached to the flywheel, and thus the oil is constrained to pass through the passage 48 to the side of the crank case and thence again to the reservoir 28.

As previously stated the pressure is regulated by a spring-controlled valve. This

pressure must be just sufficient to overcome the resistance to the flow through the smallest of the passages, which has a diameter of $\frac{1}{8}$ in., and to raise the oil as far as the big end of the connecting rod. When the motor, through running at a high speed, causes the pressure to unduly rise, the valve is forced open and the excess of oil passes back to the reservoir 28 through the passage 49, thus maintaining the normal pressure of the oil.

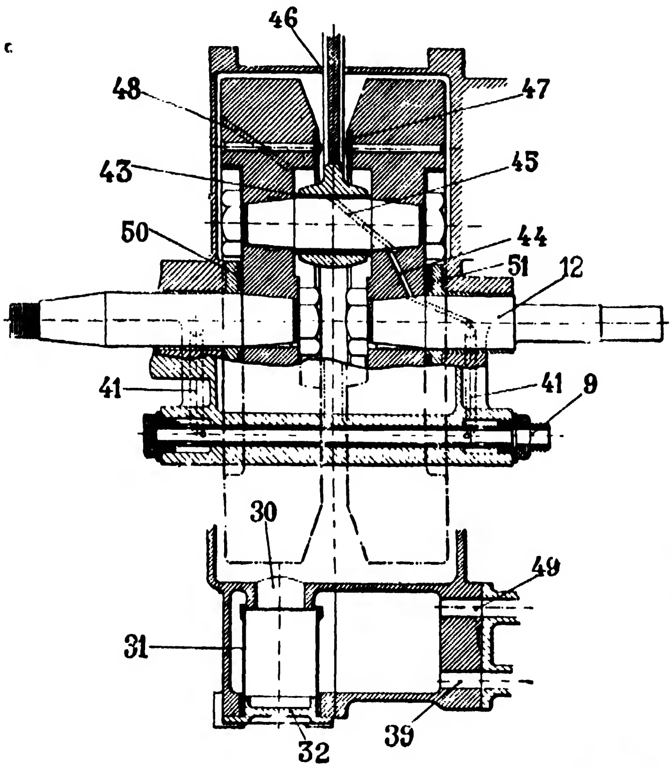


Fig. 416. Section through Crank and Casing

Engines. A type of single-cylinder engine, as fitted to the Darracq 7 h.p. car, is illustrated in fig. 417. Both valves, exhaust and inlet, are arranged on the one side, and they are mechanically operated by the timing mechanism, which is entirely enclosed. For the lubrication of the engine alone a separate oil pump of the pinion type is provided, as indicated at the extreme left of the casing.

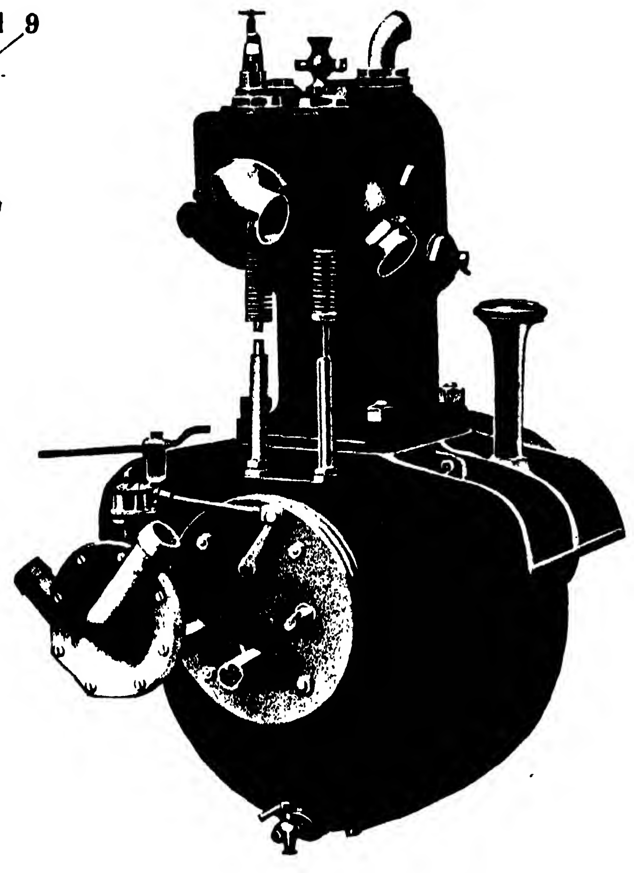


Fig. 417. - Darracq Single-cylinder Engine

Small cars of less than 8 h.p. have generally single-cylinder engines, but for larger cars the power is divided over several cylinders, according to the power required. In these engines the cylinders are usually cast in pairs and bolted to a common crank case. This construction, which is very generally adopted, is illustrated in figs. 418, 419, and 420. Fig. 418 shows the Speedwell two-cylinder engine, developing from 10 to 12 h.p.; fig. 419 is the four-cylinder engine of the same makers, developing 25 h.p.; and fig. 420 is the six-cylinder 40-h.p. type. It will be seen that the same parts are largely used throughout the various sizes. Having described in detail a single-cylinder engine, it will not be necessary to give any lengthy description of the

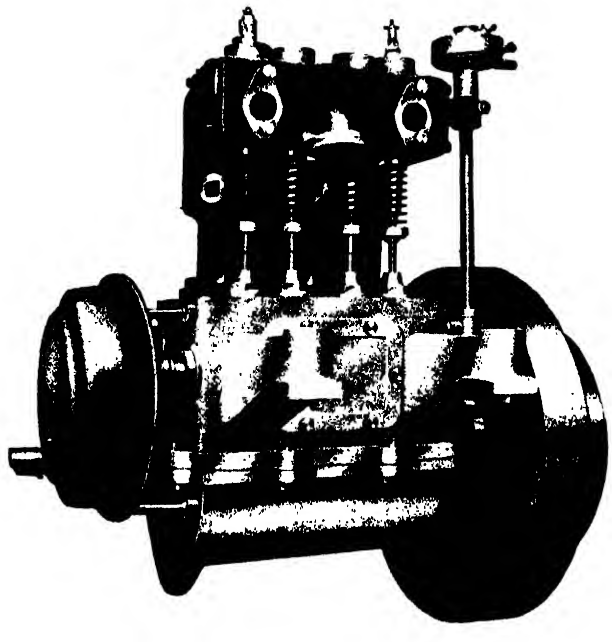


Fig. 418.—Speedwell Two-cylinder Engine

multiple-cylinder types. With one cylinder it is not possible to balance the reciprocating parts, such as the piston bucket and rod or the connecting rod, but the rotating portions may be satisfactorily dealt with by the addition of suitably-placed weights. With two or more cylinders the inertia forces of one set of reciprocating parts may be balanced

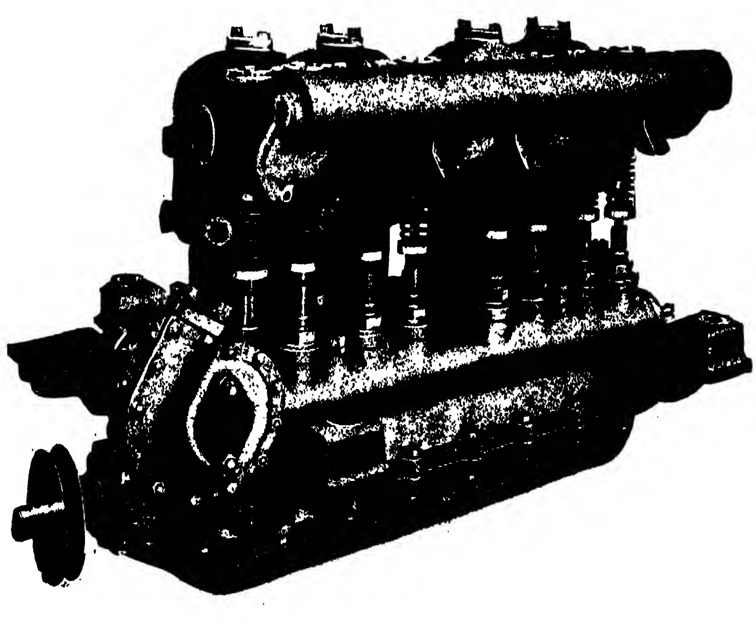


Fig. 419.—25-H.P. Four-cylinder Engine. Valve side, showing Centrifugal Pump and Gas Chamber

to a large extent by the inertia effects of other parts. By dividing the power over several cylinders, not only is it possible to reduce the weights of the various parts, but also to improve the quietness of the running, as the reciprocating masses may be almost entirely balanced amongst themselves.

Several considerations determine the order of the explosions in the various cylinders. In the double engine the explosions may be arranged to occur at intervals of one revolution, or two strokes, in which case the torque to which the shaft is subjected is most uniform; or they may be timed to take place at intervals of one stroke and three strokes alternately, in which case the best balancing of the reciprocating parts

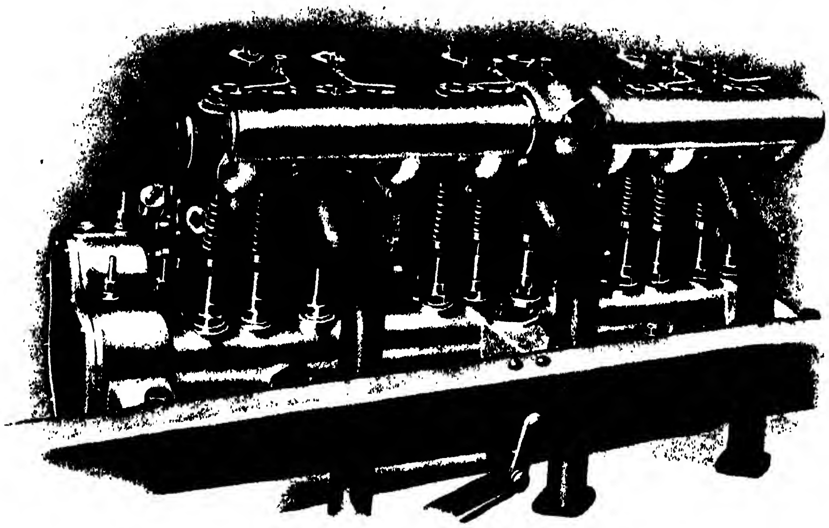


Fig. 420.—Speedwell Six-cylinder Engine

is obtained. This latter arrangement is illustrated diagrammatically in fig. 421, where the relative positions of the pistons are indicated for each stroke of the cycle I to IV inclusive. At stroke I the charge in cylinder a has been compressed during the previous stroke, and is ready for the explosion, while in cylinder b the waste gases resulting from the previous explosion stroke are about to be exhausted. At stroke II exhaust is

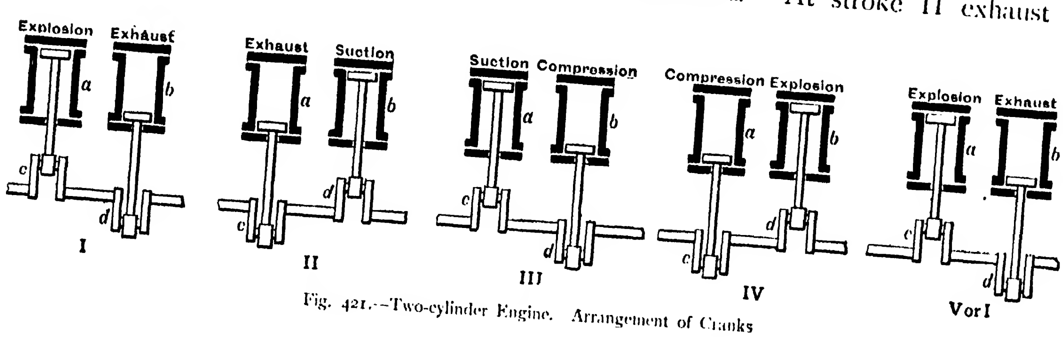


Fig. 421.—Two-cylinder Engine. Arrangement of Cranks

commencing in cylinder a, and the suction of a new charge in b. At III suction is commencing in a and compression in b, while at the fourth stroke the charge in a is about to be compressed, and the explosion is occurring in b. The following stroke commences the new cycle, and is a repetition of stroke I.

It will be observed that explosions take place consecutively in stages IV and V, whereas between the explosions of stages I and IV there are three strokes. It will

also be noted that, owing to the arrangement of the cranks at 180° apart, the two sets of reciprocating parts have corresponding motions, but in opposite directions, so that the inertia forces are to a large extent balanced, and much of the vibration eliminated.

In the second arrangement, illustrated in fig. 422, the two cranks, instead of being spaced 180° apart, have the same position, and may therefore be combined. All the reciprocating parts now move simultaneously in the same direction, and

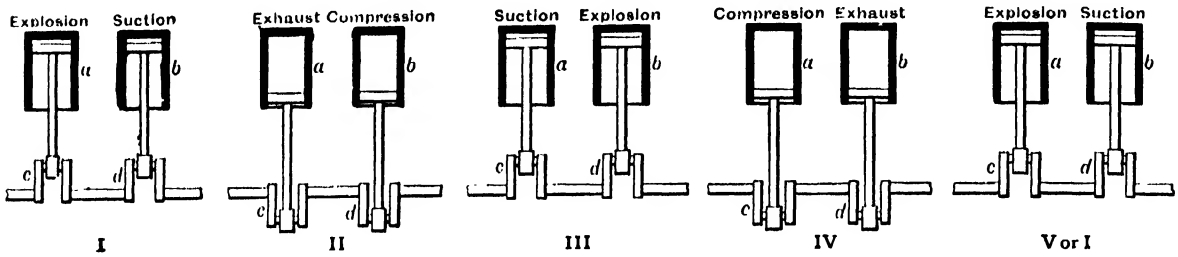


Fig. 422.—Two-cylinder Engine. Arrangement of Cranks

they cannot be made to balance one another. With this disposition of the cranks there is the advantage of a more uniform turning effort, as the explosions take place at regular intervals of one revolution. Commencing with the explosive stroke in cylinder *a*, the piston of cylinder *b* will now be at the top, and about to draw in the new charge; whereas in the previous arrangement, fig. 421, the piston was at the bottom and just about to commence the exhaust. At the second stroke, fig. 422, exhaust is commencing in cylinder *a* and compression in *b*. Stroke three of fig. 422

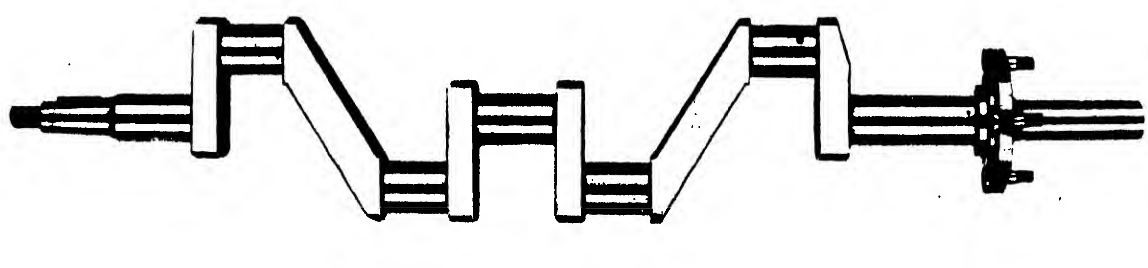


Fig. 423.—Crank Shaft of Wolseley Four-cylinder Engine

differs from the corresponding stroke of fig. 421, as the explosion in cylinder *b* of the former is about to take place.

When the engine has more than two cylinders the sequence of the explosions may be so arranged as to combine the advantages of both systems; but mechanical considerations also play a part, and there is no general order that is followed by the various makers. Some builders adopt the order of explosion in the cylinders 1, 2, 4, 3, or 1, 3, 4, 2—the latter arrangement being that used in the Siddeley car of the Wolseley Tool and Motor Car Company of Birmingham. From the illustration, fig. 423, of the crank shaft it will be seen that the first and fourth cranks are disposed

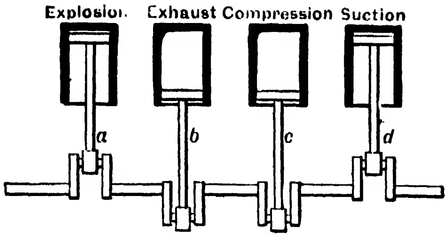


Fig. 424.—Four-cylinder Engine Crank Arrangement

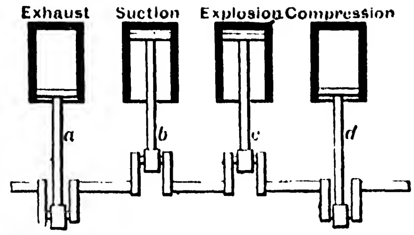


Fig. 425.—Four-cylinder Engine Crank Arrangement

at 180° to the second and third cranks, so that the reciprocating parts move together in pairs, while the inertia forces of the one pair balance those of the other. The shaft is borne in bearings placed between the second and third cranks and at the ends. Figs. 424, 425, 426, 427 illustrate diagrammatically the sequence of the actions in the

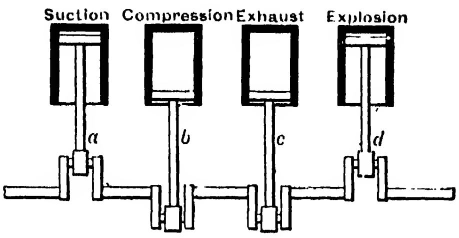


Fig. 426.—Four-cylinder Engine Crank Arrangement

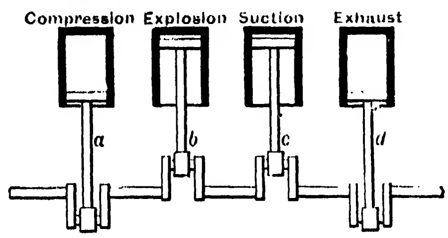


Fig. 427.—Four-cylinder Engine Crank Arrangement

cylinders throughout the four strokes which constitute one cycle. It will be seen that at each stroke there is an explosion in the first, third, fourth, and second cylinders consecutively.

As regards the arrangement of the engine, or of the crank shaft, no one of the

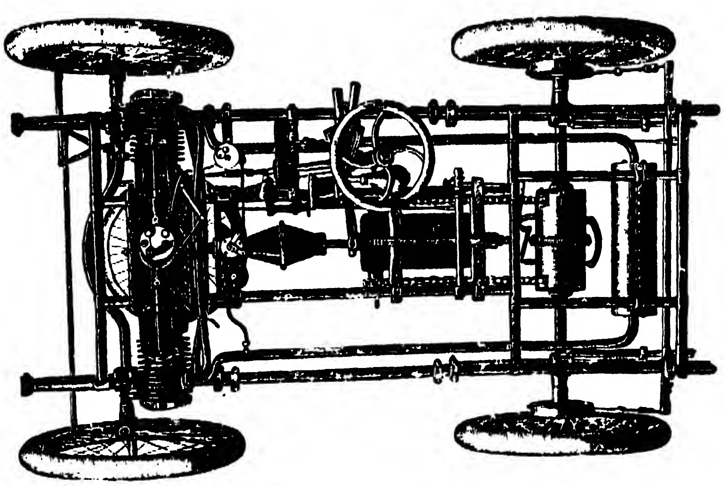


Fig. 428.—Turgan Chassis viewed from above, showing Opposed Cylinders

generally-used systems can be said to be superior to another in all respects, although the majority of cars are now fitted with longitudinal shafts and vertical cylinders placed at the front before the driver. Other arrangements are adopted in certain well-known types, as, for example, in the Arrol-Johnston engine, in which the charge

is exploded between two pistons which work in opposite directions in the cylinder. Another arrangement, adopted in the Turgan car, which is manufactured in France,

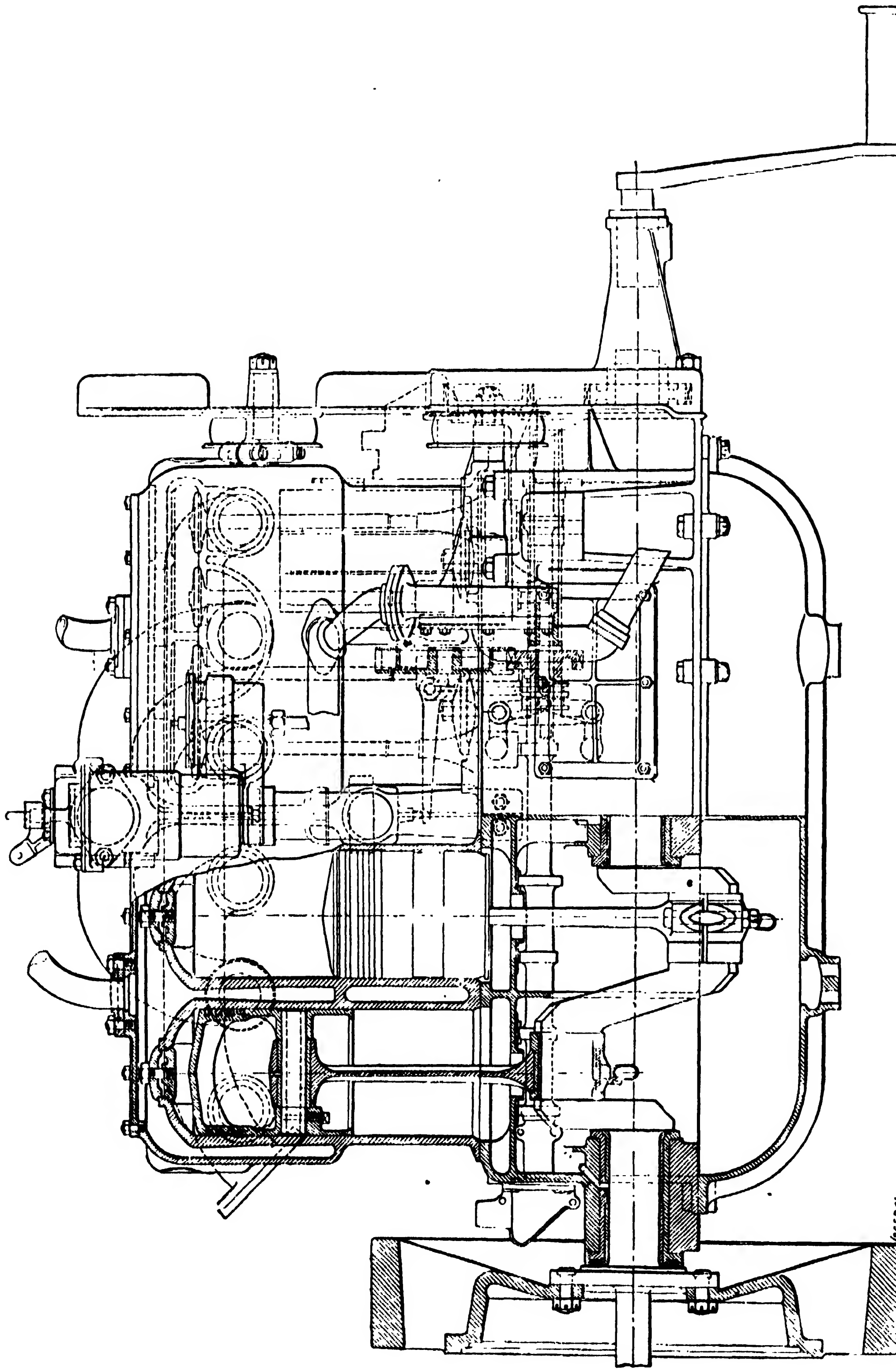


Fig. 429.—Sectional Longitudinal Elevation of Siddeley Four-cylinder Motor

is shown in fig. 428. It has a two-cylinder engine with the cylinders arranged in line across the front of the car; but this system is not generally favoured, owing to the dangerous side swing that may be induced at the front.

As an example of a four-cylinder engine the motor of the Siddeley car already referred to is illustrated in the half-sectional elevation fig. 429, the end-sectional elevation fig. 430, and the external view fig. 431. The piston bucket, with its piston rings and the connecting rod, are also illustrated in fig. 432.

From the illustrations it will be seen that the engine is of the vertical type, with the iron cylinders, water jackets, and heads cast together in pairs and mounted upon an aluminium base chamber, which forms the upper portion of the crank pit, the bottom

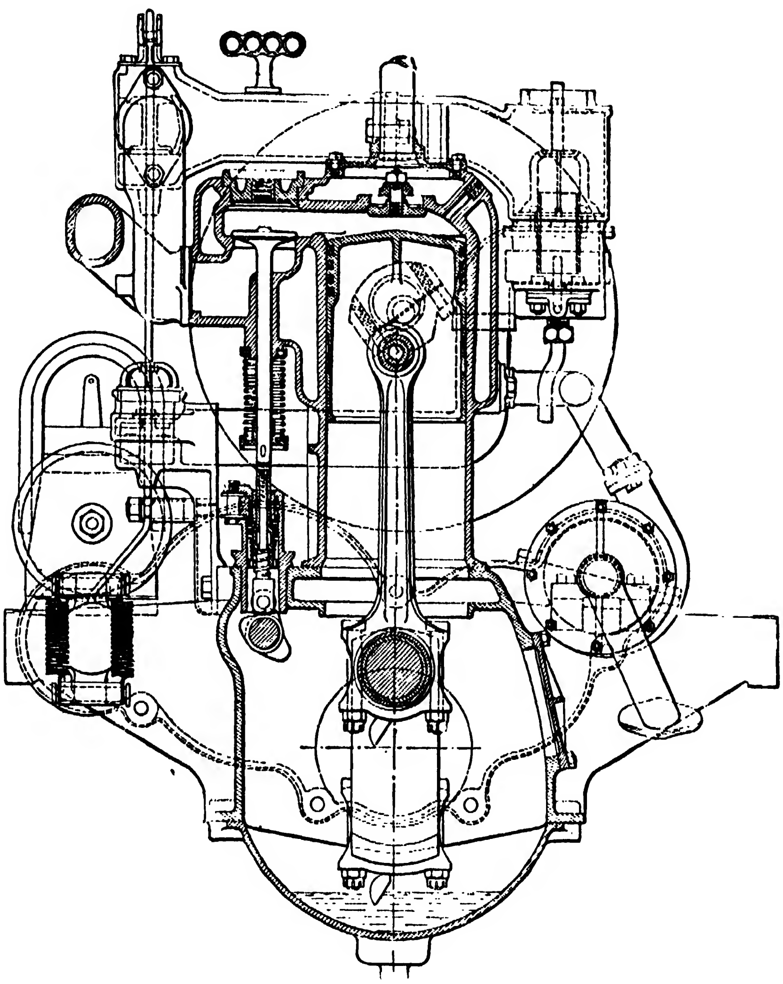


Fig. 430.—Cross Section of Siddeley Motor

being removable to facilitate inspection. All four cylinders have a diameter of 4⅛ in., with a stroke of 5 in., and at the normal speed of 1000 revolutions per minute the motor is rated at 36 brake h.p. The crank chamber is divided into two separate compartments by a partition, which prevents the lubricant from flowing completely to one end of the casing, and thus from starving certain portions of the mechanism when the car is on an inclined road. Two inspection covers and two drain holes are also provided in the lower part of the crank chamber.

All the valves for the exhaust and the admission are interchangeable, and are arranged in pairs along the one side of the motor, where they are most accessible. In the earlier types of Wolseley engines the suction valves were placed over the cylinder

top, and the exhaust valves at the bottom. Along the front of the engine, and enclosed in the crank chamber, is carried the horizontal cam shaft which operates the valve stems. At the forward end the valve shaft is driven from the main shaft by spur

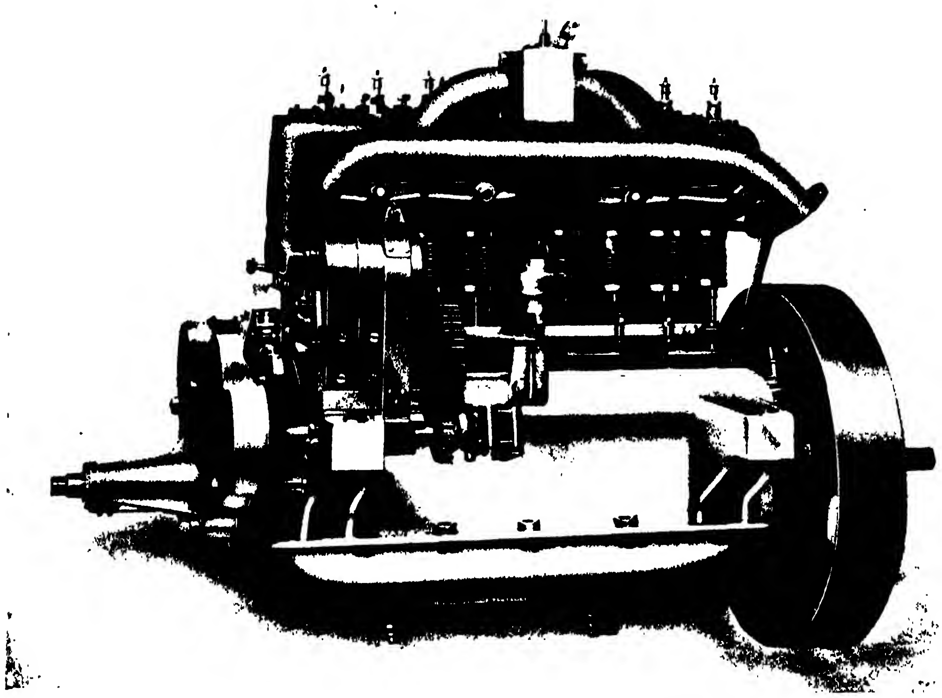


Fig. 431.—General Appearance of Wolseley Four-cylinder Engine

gears, which make the cam shaft rotate at half the speed. This shaft, with its cams, which engage with the valve spindles, is clearly indicated in the figs. 429 and 430. When running, the charge is ignited by means of the high-tension magneto attached to the casing on the valve side, as shown in fig. 431; but to facilitate the starting

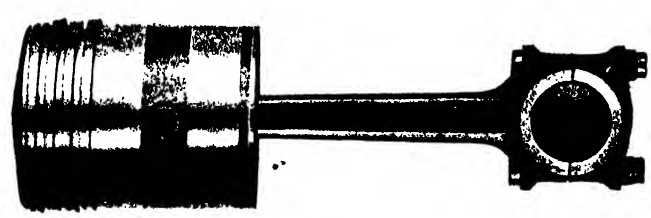


Fig. 432.—Bucket Piston of Wolseley Engine

of the motor from the cold condition, an accumulator and high-tension coil is also provided. A lever on the steering wheel enables the ignition point to be advanced or retarded, in the case at least of the magneto, by altering the position of the armature relatively to the magnetic field.

Separate control of the motor is obtained by means of a centrifugal governor, which operates a balanced throttle in the mixture pipe, and also regulates the air inlet to the carburettor. When required, the governor may be held out of action by depressing a pedal provided for this purpose. A special type of compensating carburettor is fitted midway between the two pairs of cylinders, which ensures an equal feed to each set.

When dealing with the details of carburettors, the various systems of supply will be described. In the case of the Siddeley car the petrol is stored in a reservoir, which is carried at the rear of the chassis, beside the silencer. This tank has a capacity of about 16 gal., and the supply to the carburettor is effected under the pressure of

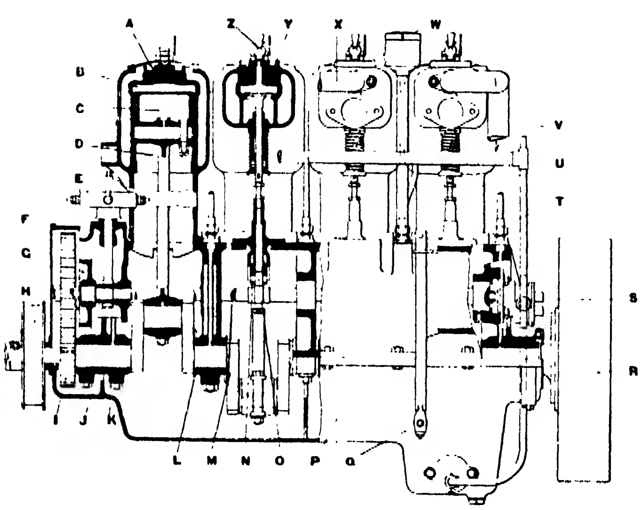


Fig. 433.- Engine of Argyll 14-16-H.P. Car, Half Sectional and Side Elevation

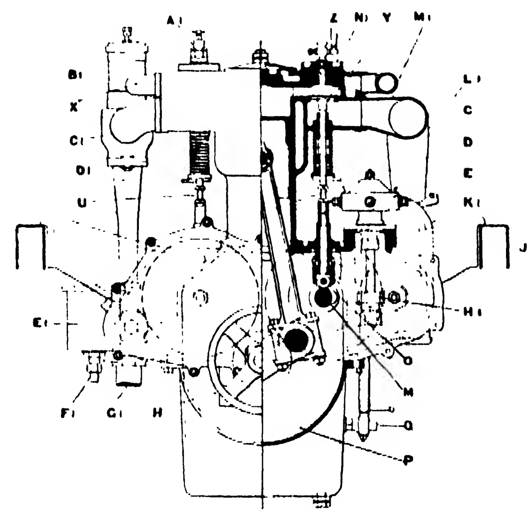


Fig. 434.- Half Sectional End Elevation

A. Cylinder plug.
B. Cylinder.
C. Piston.
D. Connecting rod.
E. Commutator.
F. Half-time wheel.
G. Magneto driving wheel.
H. Fan pulley.
I. Main-shaft timing wheel.
J. Crank shaft.
K. Crank shaft bearing covers.
L. Crank-shaft oil discs.
M. Cam shaft.
N. Valve lifter.
O. Valve-lifter roller
P. Crank case.
Q. Drain cock.
R. Flywheel.
S. Oil pump.
T. Crank-shaft lubricating unions.
U. Valve-adjusting pins.
V. Inlet to water jackets.
W. Crank-case oil filler.
X. Water-circulating pipe.
Y. Exhaust valve.
Z. Compression tap.
A_1. Sparking plug.
B_1. Combined carburettor and throttle.
C_1. Inlet pipe.
D_1. Carburettor pivot tube.
E_1. Carburettor float chamber.
F_1. Petrol inlet.
G_1. Hot air inlet.
H_1. Commutator spiral wheel.
J_1. Frame.
K_1. Magneto.
L_1. Exhaust pipe.
M_1. Water outlet to radiator.
N_1. Valve plug.

the exhaust gases, which are admitted to the reservoir through a bypass connection between it and the exhaust pipe. An automatic valve arrangement keeps the pressure in the feed system constant as the working of the engine varies, and an indicator is placed on the splashboard within the view of the driver. A hand pump is also provided to obtain the necessary initial pressure when starting.

All the parts of the engine subjected to the high temperature of the combustion are surrounded with water jackets, which are very clearly indicated in figs. 429 and 430. Cold water from the radiator at the front of the car is drawn by a centrifugal pump, shown at the extreme right hand of fig. 430, and circulated through the jackets and thence back to the radiator, where it is again cooled.

Forged steel is used for the connecting rods, and also for the crank shaft, fig. 423, which is carried in three gun-metal bushes lined with white metal. Each bearing is lubricated through a separate pipe in connection with a common oil tank on the

splashboard, and the big ends of the connecting rods have in addition a small pipe which dips at each revolution into the oil contained in the bottom of the crank case, and in this way a continuous supply of oil is forced up as far as the crank pin.

An Argyll four-cylinder 14 16-h.p. engine is illustrated in figs. 433 and 434, which show in half-sectional side and end elevations the arrangement of the mechanism and the details of the cylinders and the valves. Fig. 433 shows one cylinder and one valve in section, and fig. 434 shows in the same way one cylinder with its inlet valve.

It will be seen from the illustrations that the engine is hung directly from the main frame J_1, upon brackets cast in one piece with the upper portion of the engine casing. Three piston rings are fitted to each of the pistons C, and the gudgeon pins are secured

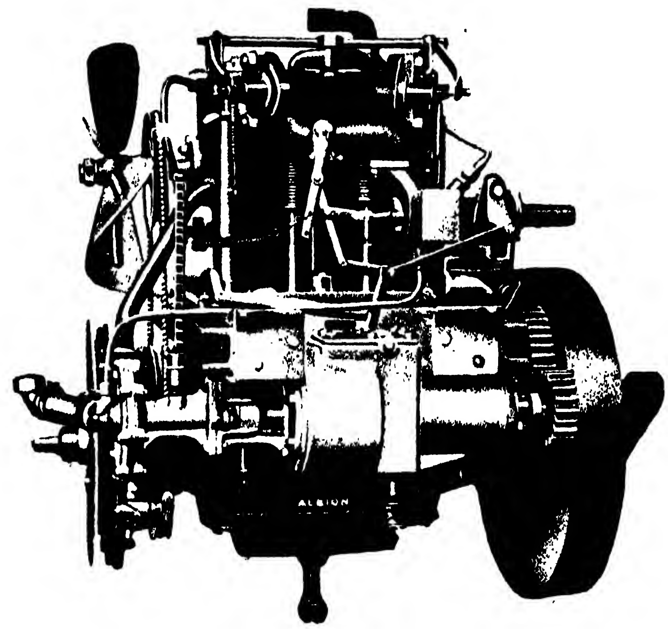


Fig. 435.—General Appearance of Albion 16-H.P. Engine

with special lock pins shown in fig. 433. Forged steel is used for the connecting rods, which are turned to a circular section of ample strength, and the crank shaft is of steel turned from a solid forging and ground to size. Each crank is supported on either side by a bearing, and the alignment of the shaft does not readily wear out of truth. Splash lubrication is adopted, but in the case of the shaft bearings oil is supplied from the reservoir on the splashboard through connections T. A partition in the lower portion of the crank case prevents the oil which it contains from flowing to one end when the car is on an incline, and thus avoids the danger of unequal lubrication. All the valves are alike and interchangeable, and being arranged on opposite sides of the engine, the exhaust on the one side and the admission on the other, two half-time shafts are required. These are shown in the figures at M, running within the casing and geared to the crank shaft by the 1 to 2 gear wheels F and I. The valve lifters N are provided with anti-friction rollers O, and the lift of each may be adjusted by means of a screw and lock nut. Ignition is effected electrically by means of a magneto working in conjunction with the commutator E, which controls the sequence of the explosions in the various cylinders.

Several novel arrangements, which will be dealt with later under their respective headings, are embodied in the Albion motor. Fig. 435 is an external view of the engine, complete with all its gear, as fitted to the Albion 16-h.p. car. The motor is of the two-cylinder vertical balanced type, having cylinders $4\frac{7}{8}$ in. diameter and 5 in. stroke, developing 16 h.p. Splash lubrication is only used for the minor bearings, the cylinders,

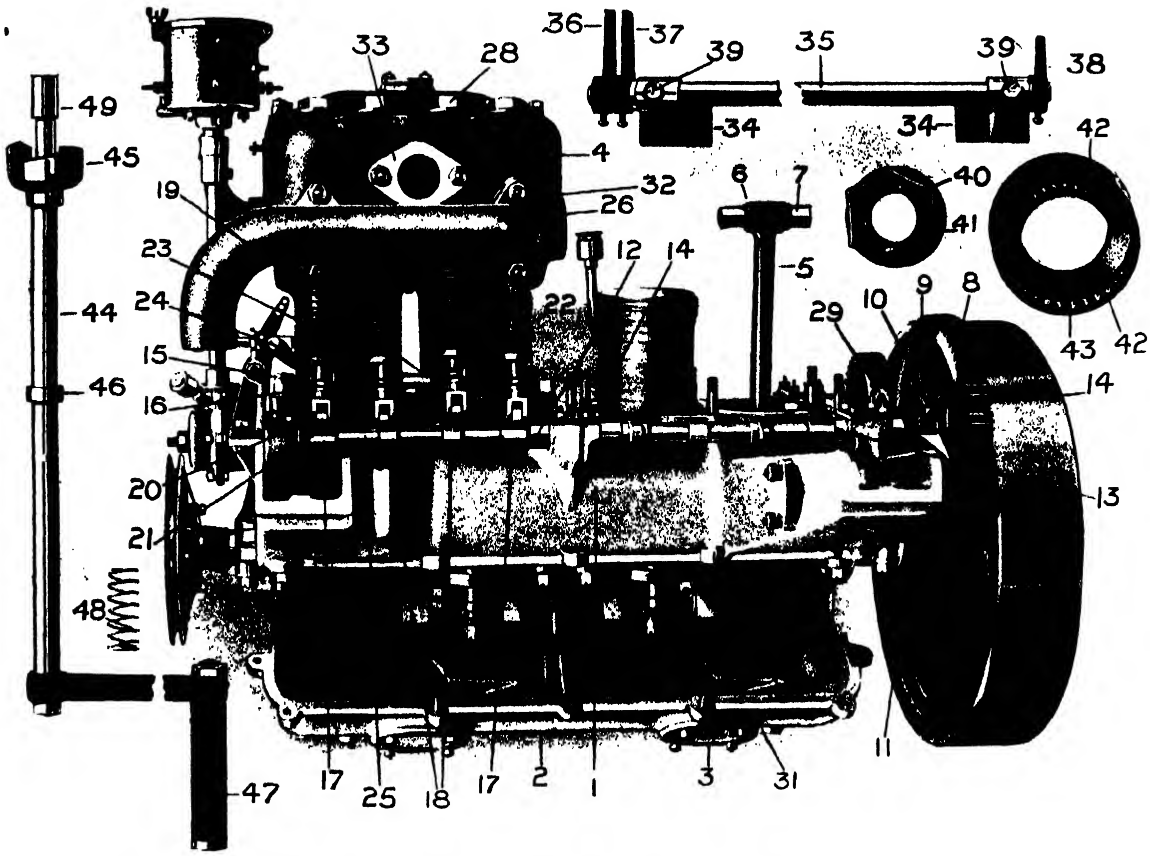


Fig. 436.—Daimler Four-cylinder Engine, Valve Side

1. Top part of base chamber.
2. Bottom part of base chamber.
3. Inspection-hole cover.
4. Cylinders. Valve guides. Bushes for valve guides.
5. Connecting rod.
6. Bush for connecting rod.
7. Gudgeon pin.
8. Fibre portion of half-speed wheel.
9. Ring for half-speed wheel.
10. Centre portion of half-speed wheel.
11. Half-speed pinion on crank shaft.
12. Middle bearing for cam shaft.
13. Bearing for gear-wheel end of cam shaft and ignition shaft.
14. Cam-shaft bracket covers.
15. Valve-lever adjusting screw.
16. Nut for adjusting screw.
17. Exhaust cam.
18. Induction cam.
19. Tube shaft for valve levers.
20. Valve lever.
21. Roller for valve lever.
22. Valve (induction and exhaust). Collar for valve. Cotter for valve.
23. Spring for valve.
24. Tube shaft bracket covers.
25. Cam shaft.
26. Exhaust pipe (L.H.).
28. Plug for cylinder head.
29. Intermediate wheel.
31. Joint for inspection hole cover.
32. Joint for exhaust flange.
33. Joint for inlet flange.
34. Control brackets.
35. Control shaft.
36. Magneto lever.
37. Control tube actuating lever.
38. Lever for carburettor.
39. Lubricator (No. 26) for control bracket.
40. Nut for crank shaft.
41. Washer for nut of crank shaft.
42. Ballrace for crank shaft.
43. Balls for ballrace.
44. Shaft for starting handle.
45. Starting claw.
46. Collar for starting handle shaft.
47. Starting lever. Starting handle bolt. Nut for starting handle bolt. Sleeve for starting-handle bolt.
48. Spring for starting-handle shaft.
49. Bush for starting-handle shaft.

main bearings, and crank pins being respectively lubricated by a special type of mechanical pump lubricator, which ensures at all speeds of the engine a sufficient supply to each of the main bearings, and entirely does away with all smoky exhaust. Relief cams are provided to facilitate the starting of the engine, and the two half-time shafts, for operating the valves on the two sides, are entirely enclosed, together with their gear wheels. The motor is governed on the inlet by the Murray governor, which automatically regulates the speed, mixture, and ignition advance. These are controlled together by a single

hand lever, which replaces the three separate levers commonly provided. Hand adjustment of the mixture is also provided, to meet the requirements of varying atmospheric conditions and different grades of fuel. Further particulars will be given later of the

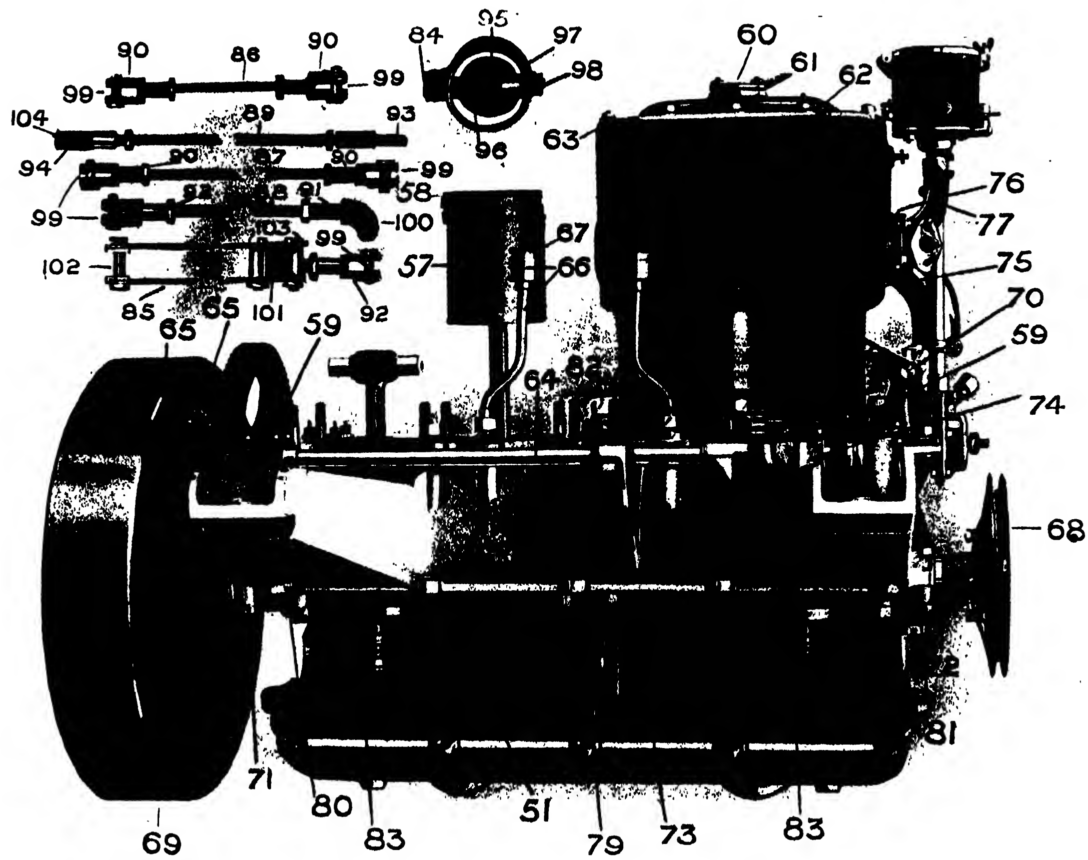


Fig. 437.—Daimler Four-cylinder Engine, Half-time Shaft Side

51. Crank shaft
57. Piston
58. Piston rings.
59. Pump-shaft bearing covers.
60. Flanges for cylinder covers.
61. Joints for cylinder-cover flange.
62. Cylinder cover.
63. Cylinder-cover joint.
64. Pump-driving shaft.
65. { Fibre wheel for pump-driving shaft. / Wheel centre.
66. { Oil-filling cup / Tube for oil-filling cup.
67. Cap for oil filling cup.
68. Fan pulley.
69. Flywheel.
70. Control shaft.
71. Rear-end bearing (in halves).
72. Front-end bearings (in halves).
73. Middle bearings (in halves).
74. Lay-shaft bearing (front end).
75. Pet cocks.
76. Joint for cylinder side covers.
77. Plug for cylinder (front end).
79. Cap for centre bearing.
80. Cap for flywheel-end bearing.
81. Cap for front-end bearing.
82. Magneto driving wheel.
83. { Connecting-rod bearing (top half). / Connecting-rod bearing (bottom half).
84. Lever for exhaust throttle.
85. Connecting rods to throttle.
86. Connecting rod to magneto.
87. Connecting rod to steering column.
88. Connecting rod to ignition.
89. Connecting rod to exhaust throttle.
90. Jaws for magneto connecting rod.
91. Jaw for ignition connecting rod.
92. Jaw for ignition connecting rod and distance piece.
93. Jaw for exhaust throttle connecting rod.
94. Jaw for exhaust throttle connecting rod.
95. Exhaust throttle.
96. Exhaust-throttle spindle.
97. Ring for exhaust throttle.
98. Collar for exhaust-throttle spindle.
99. Joint pins for jaws of connecting rods.
100. Joint pin for carburettor lever and jaw for ignition connecting rod.
101. Connecting-rod distance piece.
102. Pin for connecting rods to throttle.
103. Bolts for connecting-rod distance piece.
104. Joint pin for jaw for exhaust-throttle connecting rod.

governing, ignition, and lubricating arrangements which form the subjects of various Albion patents.

In the two illustrations given of the Daimler four-cylinder engine every detail is clearly indicated, and the name specified in the list of parts. To expose the various internal parts, portions of the engine have been dismantled. Fig. 436 shows the valve side of the engine, and fig. 437 the half-time shaft side.

Carburettors.—Until the oil supply is mixed with air, in the proportions necessary for its combustion, no explosion can be obtained from it in the cylinder of the engine; and it is further necessary, in order to obtain a sufficiently rapid combination, that the air and petrol should be very intimately mixed, so that each minute globule of the oil may be surrounded by sufficient air for its combustion.

These two requirements are satisfied by the carburettor, in which the petrol is atomized or vaporized in a stream of air. For any particular quality a definite proportion of air is required, but it is not possible to completely fix the proportions of the mixtures; because, however constant the composition of the oil may be, the density of the air varies with the weather conditions. It may be very dry, or contain a very considerable percentage of water vapour, and its temperature and density may vary within wide limits. In most cars these difficulties are overcome by producing in the carburettor a mixture that is too rich, and then diluting it to the required degree with air admitted through additional air inlets, preferably under the control of the driver. In warm, dry weather the inlet may require to be fully opened, whereas in cold, foggy weather the engine will probably run best with the additional air supply cut off. Means must also be provided for controlling the quantity of the mixture, as the demands of the engine vary, either by means of a governor acting upon a throttle valve in the connection to the motor, or by hand, or in both these ways.

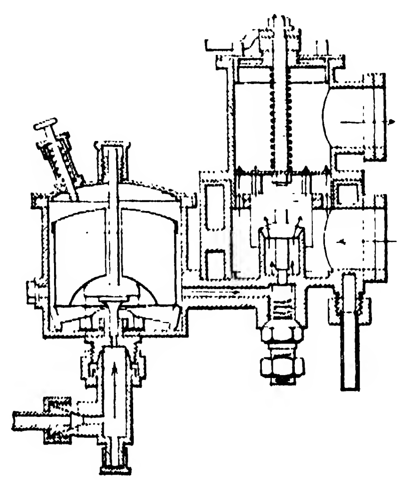


Fig. 438.—Longuemare Carburettor

Space will not permit of any description of the earlier types of surface carburettors, in which the oil was vaporized by a stream of air in its passage over the surface of the liquid. In other arrangements the air was brought into contact with the oil soaked up by wicks; but these devices have almost entirely been displaced by the spray type of carburettor. One well-known arrangement, the Longuemare carburettor, is shown in fig. 438. It consists essentially of two portions, one the carburettor proper, in which the oil is vaporized and intimately mixed with the air in the correct proportions, and the other a float chamber which controls the supply of petrol to the carburettor. The oil is admitted through the connection indicated in the figure whenever the level in the reservoir falls below a certain point. When this occurs, the float depresses the return levers, which raise the oil-admission valve. At each suction stroke of the engine piston, oil is drawn from the float chamber through the carburettor valve in a fine jet, and at the same time a stream of air is sucked in through the air inlet. The mixture of oil vapour and air is then drawn into the working cylinder and exploded. Since the readiness with which the oil vaporizes, and therefore the richness of the mixture, depends upon the temperature, it is customary to maintain as constant a temperature at the carburettor as possible by circulating hot water from the engine jackets, or the hot exhaust gases, around the jet chamber, as shown in the illustration. If the engine has been standing for some time, and the cylinder spaces have become filled with

comparatively pure air, it may be necessary to correspondingly increase the richness of the mixture by flooding the carburettor. This may be done by depressing the plunger at the top of the float chamber, thus lowering the float and opening the valve.

Under normal conditions, when the car is level the oil will stand at equal heights in the float chamber and the carburettor nozzle, usually $\frac{1}{16}$ in. from the top of the jet. This, however, will no longer be the case if the car is on an incline, as the liquid will either drain back to the chamber or flood the nozzle. If the two parts of the carburettor are placed one before the other in the lengthwise direction of the car, the oil level will be affected on a gradient; and if, on the other hand, they are arranged side by side, the level will also be affected when, for any reason, the car is tilted sideways.

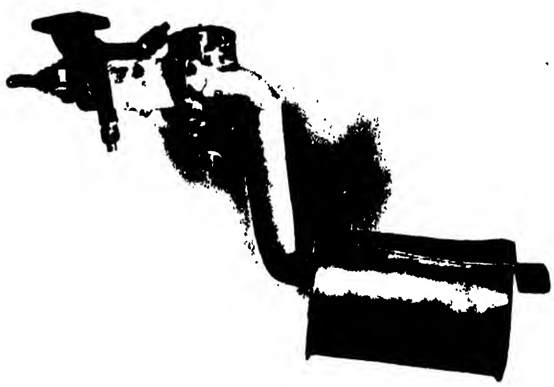


Fig. 439. Automatic Carburettor and Suction Silencer (Albion)

In the De Dion carburettor this difficulty is overcome by making the float chamber concentric with the jet, so that any change of levels affects both equally.

In the Albion carburettor, of which several views are given, the correct proportions of the gas and air, previously determined experimentally for various speeds, are automatically provided under all conditions. There are two extra air ports, one port being opened or closed by the governor as the speed of the engine changes and the other as the load on the motor varies. To allow for variations of the atmospheric conditions, and in the quality of the oil, a special hand-controlled inlet is now provided, so that the mixture may be suitably adjusted. Thereafter the governor regulates the action. To prevent freezing in cold weather a hot-water jacket is formed around the carburettor. Fig. 439 is an external view of the arrangement, with the air-inlet silencer in place, and fig. 440 shows the parts, including the governor valve, in section. Referring to the figure, the petrol passes from the float feed chamber through the fine hole A_1, where it is vaporized by a stream of heated air, drawn in through the orifice A_2, and then passes through the hollow piston valve A_4 to the inlet passage A_3. From the results of previous experimental determinations the passage A_2 is designed to pass the air required for a good mixture at slow speeds and light loads. As the speed of the engine increases more air is required, and this is admitted in the proper proportion for each speed through the triangular port A_6, called the speed air port, the cover of which is operated by the governor acting on the lever A_7. When the engine is under full load the

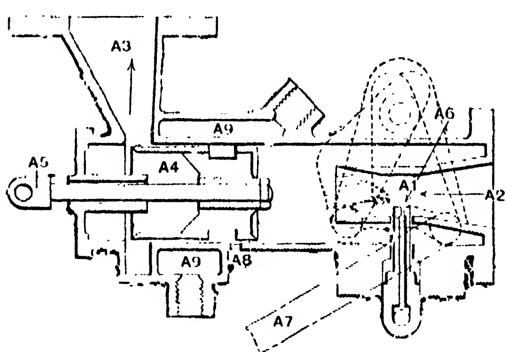


Fig. 440.- Albion Carburettor

A_1, Petrol jet; A_2, Fixed air inlet; A_3, Induction pipe; A_4, Governor valve; A_5, Governor valve spindle; A_6, Speed air inlet; A_7, Lever for operating speed air inlet; A_8, Load air inlet; A_9, Hot water jacket

combined openings of the ports A_2 and A_6 are no longer sufficient for economical working, and a third opening, called the load air port, is therefore provided. It is opened by the governor valve proportionately to the opening of the main throttle valve A_4. These three ports together give automatically a mixture of the correct proportions to suit the variations of the speed and load. As already stated, a further hand adjustment is provided to suit variations of the weather conditions. At A_9 is shown the hot-water jacket, which prevents freezing at the portions subjected to the low temperature of evaporation, especially in very cold weather.

Ignition.—Electric ignition has entirely displaced the early arrangements, in which the mixture was fired in contact with a platinum tube heated externally by means of an oil burner.

At the present time the system universally adopted consists in passing an electric spark through the explosive mixture in the cylinder at the required moment, and thus exploding it. This spark is produced between two platinum points protruding into the combustion chamber, and separated from one another by a gap, across which the spark jumps, provided the current has a sufficient pressure to overcome the resistance, which is very considerable. It is in the method of producing the required pressure, or voltage as it is called, that the various ignition systems differ. A very high pressure gives a thin intense spark, which is not so suitable as a bulky spark produced at a voltage just sufficient to pierce with certainty the gas between the points of the sparking plug.

There are two general ways of producing the necessary current in the ignition circuit.

(*a*) By means of batteries of either primary or secondary cells.

(*b*) Mechanically, from a magneto driven by the engine itself.

A single primary battery gives a pressure of only about $1\frac{1}{2}$ volt, and a secondary cell or accumulator gives at the most 2.2 volts. To derive, therefore, the necessary pressure directly from cells is not practicable, owing to the large number that would be required, and means must be adopted for transforming the low-pressure current into a high-tension current.

Electrical energy is proportional not only to the quantity of the current, but also to its pressure; and so long as the product of these is constant the quantity of energy is not changed. It may consist of a large quantity of current at a low voltage, or of a small current at a proportionately high voltage, and these may be readily transformed by means of the induction coil, which can be only very briefly described here.

Two separate coils are wound round a soft-iron core, which merely intensifies the action. One of these coils, the primary coil, consists of a comparatively few turns of stout wire, while the other, the secondary coil, is composed of a great number of turns of very fine wire. When the low-voltage current from a cell is allowed to circulate in the small coil, it induces, momentarily, in the secondary coil, an entirely separate current, having a high voltage, which depends upon the ratio of the numbers of the turns. In the same way, at the moment when the primary current is stopped another momentary current is induced in the secondary winding. Each make and each break of the primary circuit thus induces the same momentary high-tension current in the secondary coil;

but the two induced currents flow in opposite directions, and neither is sufficiently intense to jump the gap at the sparking plug. In the induction coil a condenser, consisting of two alternate series of insulated tinfoil sheets, is added as a shunt across the contact maker of the primary circuit, and as a result the current at the make takes longer to grow, being opposed by the condenser, while the opposite current, at the break, dies away instantly, being assisted by the condenser. As the suddenness with which the current rises or falls really determines the induced pressure, the current at the make, with the condenser in use, is comparatively feeble, while the current induced at the breaking of the primary circuit is sufficiently intense to jump the gap in a torrent of sparks.

In its simplest form the induction coil thus consists of (*a*) a primary circuit, including the battery; an automatic "make and break", or trembler, bridged by the condenser and the primary coil; (*b*) a secondary winding containing the sparking plug.

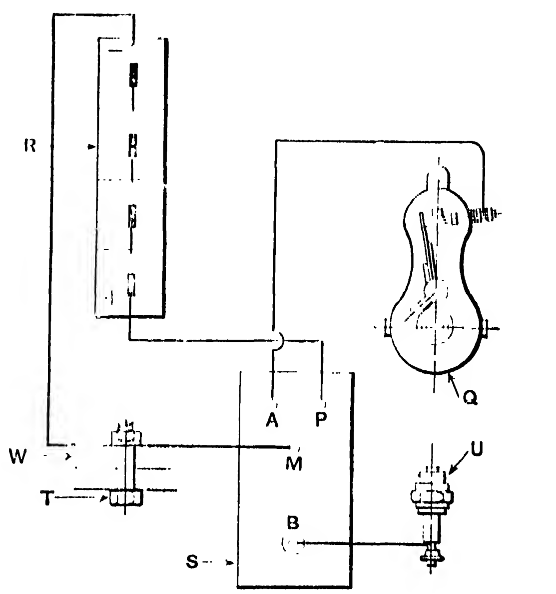


Fig. 441. De Dion-Bouton Ignition Gear Electrical Connections

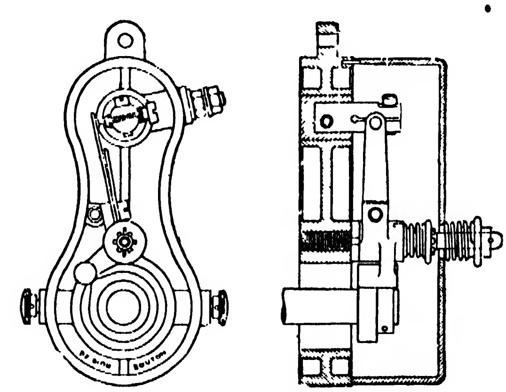


Fig. 442. De Dion-Bouton Contact Maker

It is not possible here to enter into any detailed description of the induction, or, as it is frequently called, Ruhmkorff coil, or to describe the various types of batteries and accumulators.

Two kinds of contact makers are used. One type is represented to some extent by the De Dion make-and-break arrangement, and the other by the more generally used "wipe" contact maker.

In fig. 441 the electrical connections of the De Dion ignition gear are diagrammatically represented. R is the battery of four dry cells, which is connected to the primary winding of the induction coil S through the contact maker Q. To save wiring, the current flows back to the cells through the metal work of the car, to which the other pole of the battery is attached. U is the sparking plug, connected directly to one end of the secondary coil and through the earth to the other end. Fig. 442 shows the contact maker, which consists of a pivoted spring blade, the end of which makes and breaks contact with a platinum-tipped point each time a small projection on the half-time shaft acts upon the end of the blade arm. At the moment of the break the springy

arm, by vibrating rapidly, makes a number of quick contacts, and thus produces a torrent of sparks at the plug, instead of one single spark as in other types of simple contact breakers. As already mentioned, the current from the contact maker flows back to the battery through the metal portions of the gear.

It is desirable to be able to advance or retard the ignition, that is, to make it occur at an earlier or later period relatively to that of the piston. This is effected in the De Dion and other similar contact makers by slightly rotating the contact maker relatively to the cam projection on the half-time shaft.

In the wipe arrangement the contact arm rubs over the contact surface at definite intervals; and, as the contact pieces have some length, a rapid series of sparks is obtained, as in the vibrating-blade contact maker already described. A spring is provided, as shown in fig. 443, to keep the contact arm against the surface over which

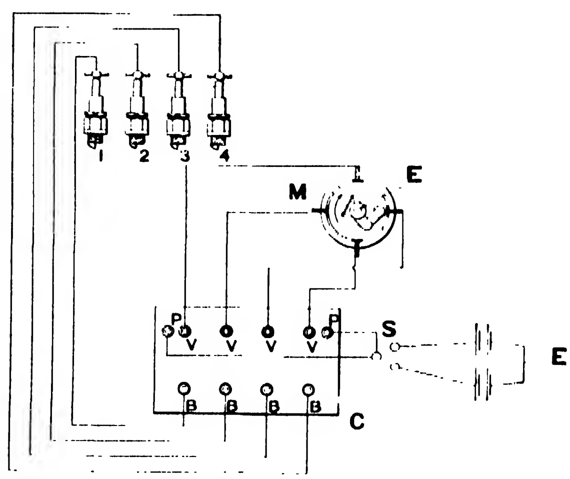


Fig. 443.—Argyll High-tension Ignition System for Four-cylinder Engine

S, Two-way Switch; C, Induction coil; M, Commutator; E, Earth connections; 1, 2, 3, 4, Sparking plugs (one for each cylinder).

it rubs. This figure shows the arrangements for a four-cylinder engine, each cylinder of which is provided with a separate ignition gear. Two sets of accumulators, one working and one spare, are indicated, with a switch at the side of the coil box for switching one or other into the circuit. Four separate coils contained in one case are provided, one for each cylinder, and each coil works in conjunction with one contact of the commutator or combined contact breaker. The sparking plugs are shown connected to the terminals B of their respective secondary coils.

A single coil may be used for the four cylinders by placing the commutator, or, as it is then called, the distributor, in the high-tension circuit, as shown in fig. 444. As before, two sets of accumulators are provided with a suitable switch; but the sparking plugs are now connected to the four contacts of the distributor, and only one induction coil is used.

Magneto Ignition.—As primary batteries require renewal, and as accumulators have to be recharged at frequent intervals, it is desirable to have some other electrical source of a more mechanical nature, such as the magneto already described in the chapter devoted to electrical generators. When the engine is running, the magneto

driven by it supplies a pulsing current, which varies in intensity from a maximum to zero twice during each revolution of the armature spindle, and by suitably operating the contact maker in the same way from the engine shaft, the magneto current at the moment when it reaches its highest voltage may be distributed to the various

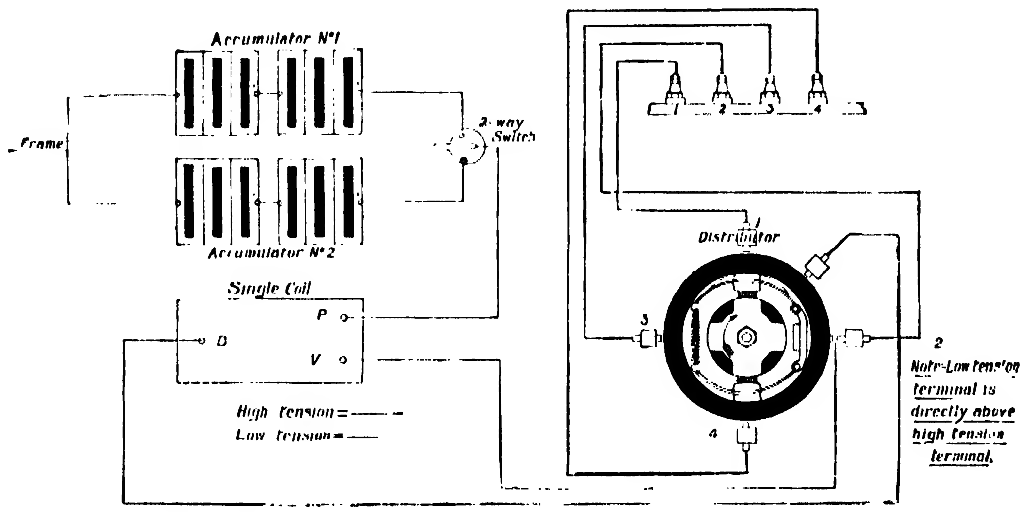


Fig. 444. Daimler Accumulator Ignition, showing arrangement of Distributor

sparking plugs in the required order. When starting the engine difficulty is sometimes experienced in obtaining the necessary current, and it is becoming very customary to fit a small coil and accumulator set as a supplementary ignition, for use when starting, and as an additional safeguard. Essentially the magneto consists of a coil

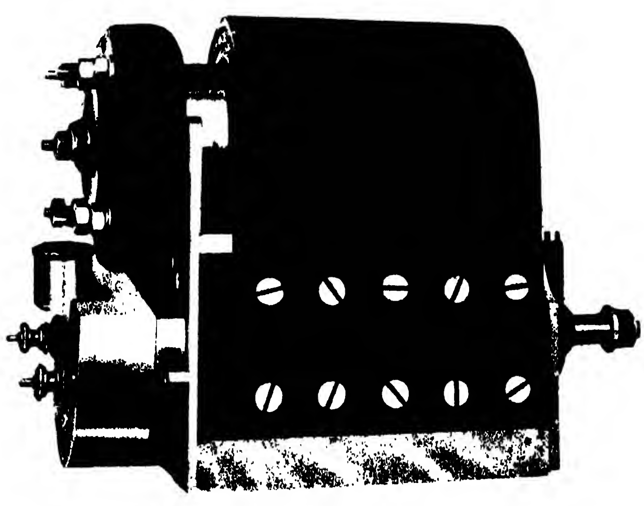


Fig. 445. Speedwell High-tension Magneto

Fig. 446.—Albion Magneto and Ignition Plug

of wire wound upon an iron core, and rotated in the magnetic field between the poles of a large multiple permanent magnet, as shown in fig. 445. Each time the coil cuts the magnetic lines of force, there is induced in it a current, the voltage of which reaches a maximum when the densest portion of the magnetic field is being cut. Instead of rotating the coil, which necessitates the use of contact rings and

brushes, the armature may be held stationary and the field rotated around it, as is done in the Albion arrangement, shown in detail in fig. 446.

By the addition of a secondary winding of many turns on the armature the comparatively low-tension current generated in the primary winding may be converted into a high-tension current, on the principle of the induction coil. Double-wound magnetos of this type are known as high-tension magnetos, to distinguish them from the low-tension ones, which have one winding only on their armatures. Ignition may be advanced or retarded at the distributor, or in some cases by suitably displacing

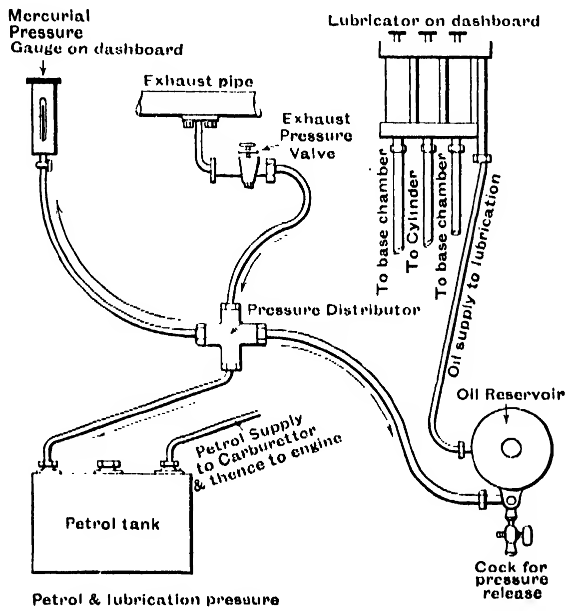


Fig. 447.—Daimler Exhaust pressure System for Petrol and Lubrication Supply

the pole shoes, which, in such cases, are constructed as movable shells around the sides of the armature.

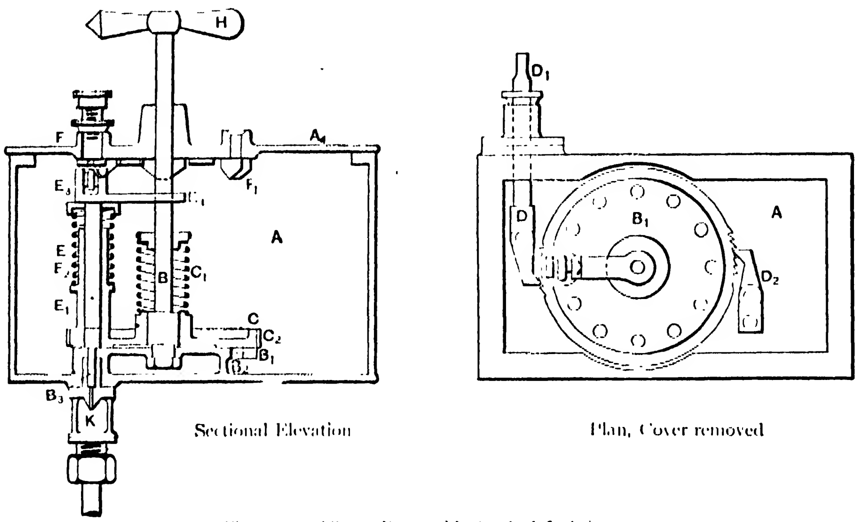
Petrol Supply.—There are two systems in common use:—

1. Gravity feed.
2. Pressure feed.

As the name implies, the petrol in the former system flows by gravity to the carburettor from the supply tank, which is placed at a higher level, generally on the dashboard in front of the driver.

In the latter case the petrol is forced from the supply tank, which may therefore be placed in any convenient position on the chassis. Hand- and mechanically-driven pumps are both frequently used to give the required pressure, and the pressure of the exhaust gases is also made use of by certain makers. The Daimler system is illustrated diagrammatically in fig. 447. In this particular arrangement the exhaust gases are used for forcing not only a supply of petrol to the carburettor, but also a supply of lubricating oil to the lubricators on the dashboard. The whole scheme is very clearly illustrated in the figure, and need not therefore be described in further detail here.

When the above-mentioned exhaust-pressure system is not adopted for the supply of the lubricating oil, valveless pumps of the simplest kind are generally used, as very serious trouble may result from any failure of this portion of the mechanism.



Sectional Elevation

Plan, Cover removed

Fig. 448. Albion Patent Mechanical Lubricator

A, Oil-retaining box; A_1, Oil-box lid; B, Central spindle; B_1, Fixed disc; B_2, Inlet port to pump; B_3, Delivery port to engine; C, Moving disc; C_1, Spring to hold C against B_1; D, Pawl, actuating C; D_1, Plunger, actuating pawl D; D_2, Pawl, preventing back rotation of C; E, Pump cylinder; E_1, Pump plunger; E_2, Spring to hold E_1 against F; E_3, Roller for pump plunger; F, Screw for regulating feed of oil.

Albion Lubricator. This lubricator, illustrated in fig. 448, is entirely automatic and is driven from the engine shaft. The box A is filled with oil through the filling cup, and as the motor rotates the pawl rod D pushes round the revolving disc C, on which is formed the pump cylinder E. Inside this pump cylinder is a piston E_1, carrying at its upper end a roller, which presses in turn against the cam projections F, F_1, F_2, &c. As the disc C and pump E are rotated by the engine, the plunger alternately rises and falls as it passes under the top projections, and alternately sucks in a supply of oil through the ports B_2 and discharges it to the various parts of the engine through the outlets B_3. Fig. 449 shows the arrangement of these inlets B_2 and outlets B_3 to the different bearings, and the method of adjusting the stroke of the piston, and therefore the oil supply, is also indicated. When the screws shown at F are screwed full out, the lubricator is arranged to deliver fifteen drops of oil per minute with the engine running at full speed. Ten drops are delivered with the screw half down, and with the screw full in the delivery is five drops per minute. As each outlet has a corresponding screw, the deliveries to the several portions of the engine may be independently adjusted. Before starting the engine, all the bearings may be lubricated by rotating the handle H. It is necessary to make provision of this kind, as the pump can otherwise only act automatically during the running of the engine.

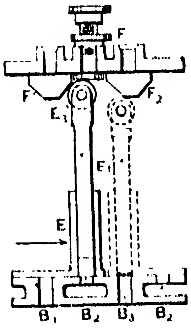


Fig. 449. Pump for Mechanical Lubricator (Albion)

B_2, Inlet to pump; B_3, Outlet from pump; E, Pump cylinder, E_1, Pump plunger; E_3, Roller for pump plunger, I, Inlet screw; I_2, Delivery cam.

Another type of valveless pump, which is also frequently used for circulating the cooling water through the jackets and the radiator, is shown in fig. 450. It is known as the Gear type, and as the name implies it consists merely of a pair of broad pinion wheels gearing together in a casing through which the oil is pumped. If by any chance the pump should become obstructed, there would be considerable danger of the breakage of some important part of the engine mechanism, and to obviate this it is customary to drive these pumps through some kind of flexible connection, such as a spiral spring,

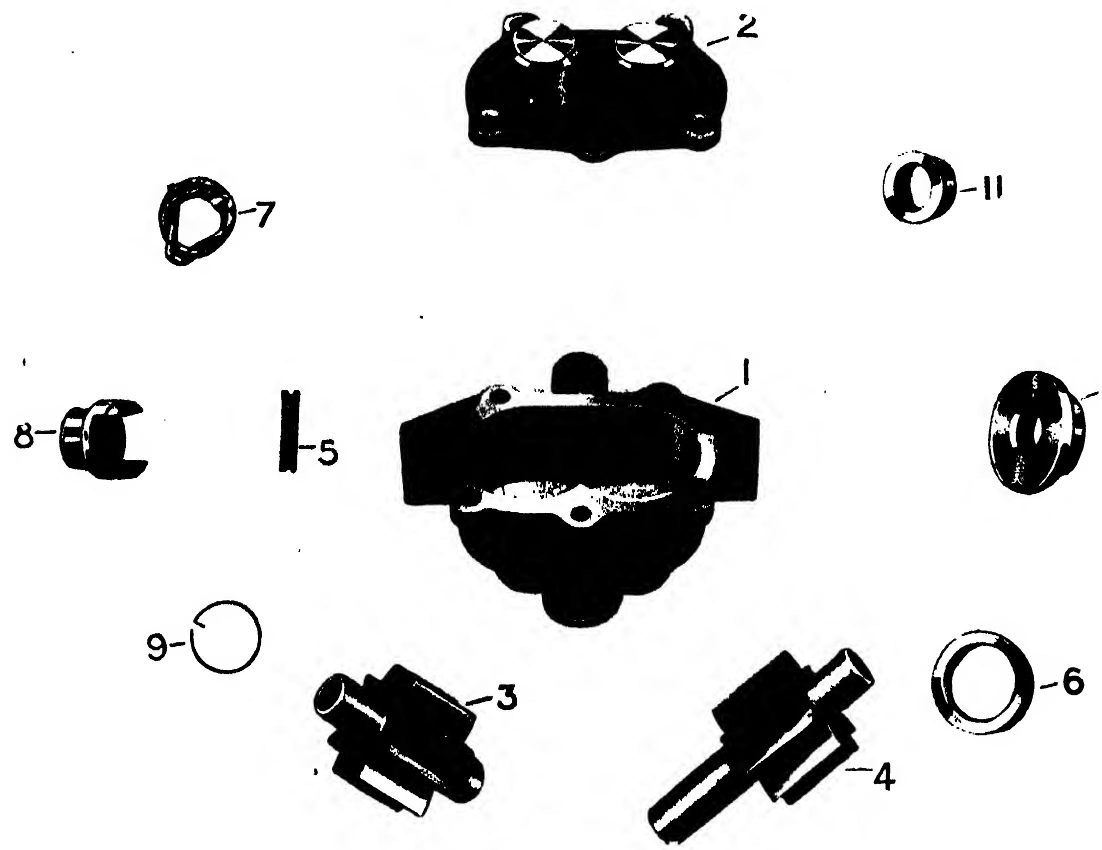


Fig. 450.—Details of Daimler Valveless Pump

1, Pump body; 2, Cover for pump; 3, Driven spur wheel (nine teeth), 4, Driving spur wheel (nine teeth); 5, Spring plate for driving plate; 6, Lock nut for gland nut; 7, Packing cotton; 8, Driving plate; 9, Spring locking ring; 10, Gland nut; 11, Collar for gland nut.

which would readily yield in the case of accident; or to insert a weak and easily replaceable part, as is done in the Daimler pump illustrated in the figure.

The Clutch Mechanism.—Before leaving the motor, and proceeding with the description of the transmission, some reference must be made to the clutch, which forms the connecting link between these two sections of the motor car. If no means of disconnecting the engine from the transmission gear were provided, the engine would require to overcome the whole inertia of the car when starting or stopping, and quick control would be impossible. By means of the clutch it is possible to disconnect the engine, and to stop the car without stopping the engine, and there are several other indirect and important advantages. One half of the clutch is attached to the motor shaft, and the other half to the main transmission shaft, from which the wheels are driven. A foot pedal placed

within convenient reach of the driver enables these two portions to be brought into contact with one another, or to be disengaged as required. The clutch, to be effective, must come into action gently to avoid shock, and yet sufficiently quickly to avoid excessive friction; and when in action it must transmit the power without slipping. It must also be so designed that it will not produce any objectionable end-thrusts upon the motor or transmission shafts while driving.

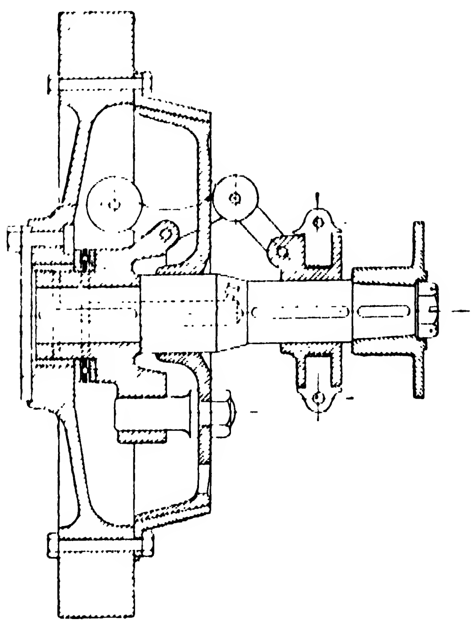


Fig. 451. "Champion" Friction Clutch

A clutch of the internal-cone type is illustrated in fig. 451. It consists of two conical portions, one fixed to the engine shaft, and one to the transmission shaft, which can be coupled together by bringing the cones into firm contact with one another. It will be evident that no end-thrusts come upon the shafts when the cones are pressed together, as would be the case if the cones were disposed in opposite directions and the one portion required to be forced into the other. In this particular clutch the cone faces are both of metal, but leather and metal contacts are very frequently adopted in other conical clutches, with springs behind the leather to improve the slipping qualities. Fig. 452 illustrates the Albion leather-to-metal clutch, together with the foot pedal T_{10} for operating it. The arrangement of the spring is such that the end-thrust does not come upon any of the shaft bearings while the clutch is in action, so that the frictional losses are reduced to a minimum, and the internal

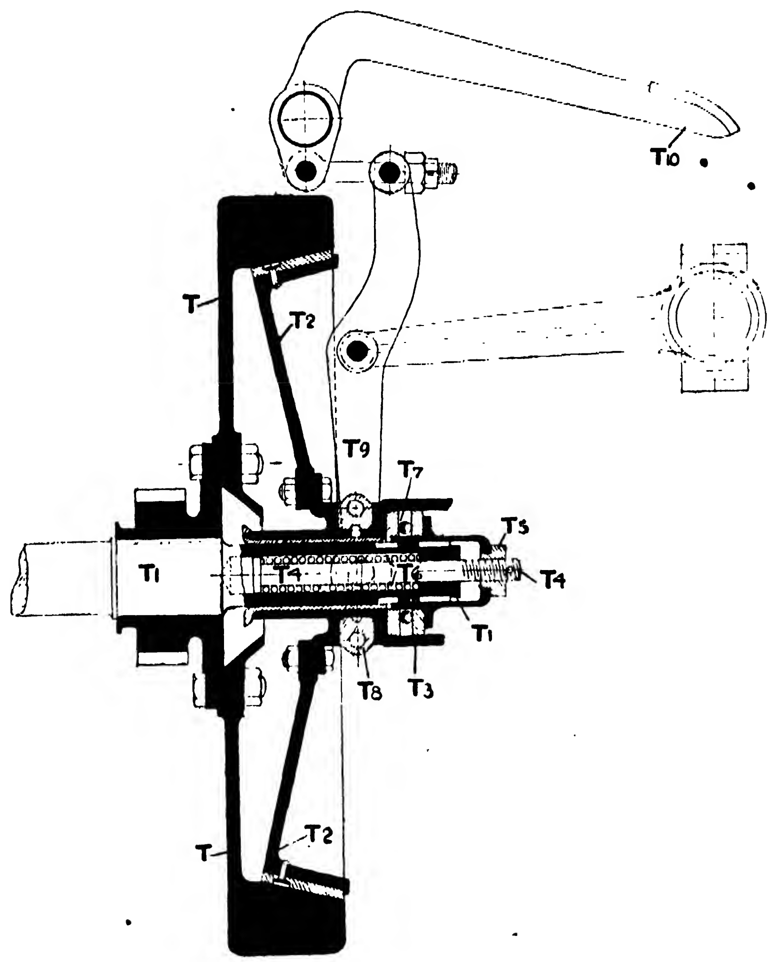


Fig. 452.—Albion Friction Clutch

T, Flywheel; T_1, End of crank shaft; T_2, Inner clutch member; T_3, Sleeve carrying T_2; T_4, Clutch bolt; T_5, Adjustment nut on T_4; T_6, Clutch spring; T_7, Ball-thrust bearing; T_8, Clutch collar; T_9, Clutch fork; T_{10}, Clutch pedal.

cone of the clutch is formed in the flywheel of the engine. Disc friction clutches are also used by many well-known makers, two examples of which are illustrated in figs. 453

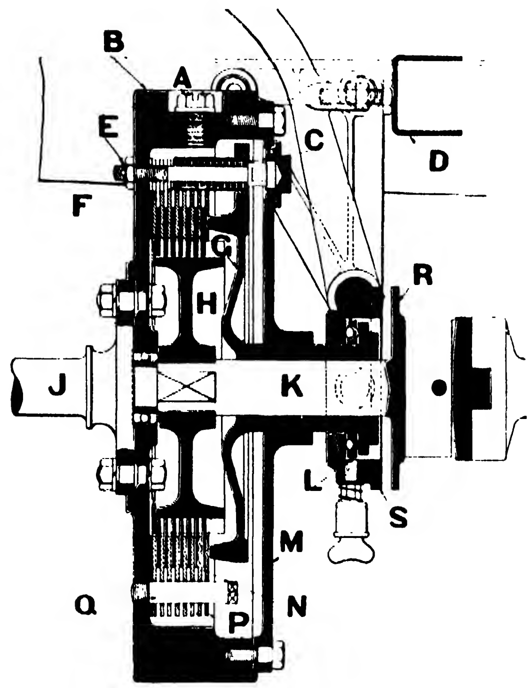


Fig. 453. Argyll Friction Clutch

A, Oil inlet; B, Flywheel; C, Clutch pressure springs; D, Chassis cross frame, E, Spring adjusting nut; F, Spring box, G, Pressure plate, H, Transmission shaft wheel; J, Engine crank shaft; K, Transmission shaft, L, Clutch collar ball race, M, Cover, N, Driven plates keyed to H; P, Driving plates; Q, Disc guide pins; R and S, Friction stopping discs.

and 454. They consist of two sets of plates or corrugated discs, arranged alternately, one set being attached to the engine shaft, and the other to the transmission shaft.

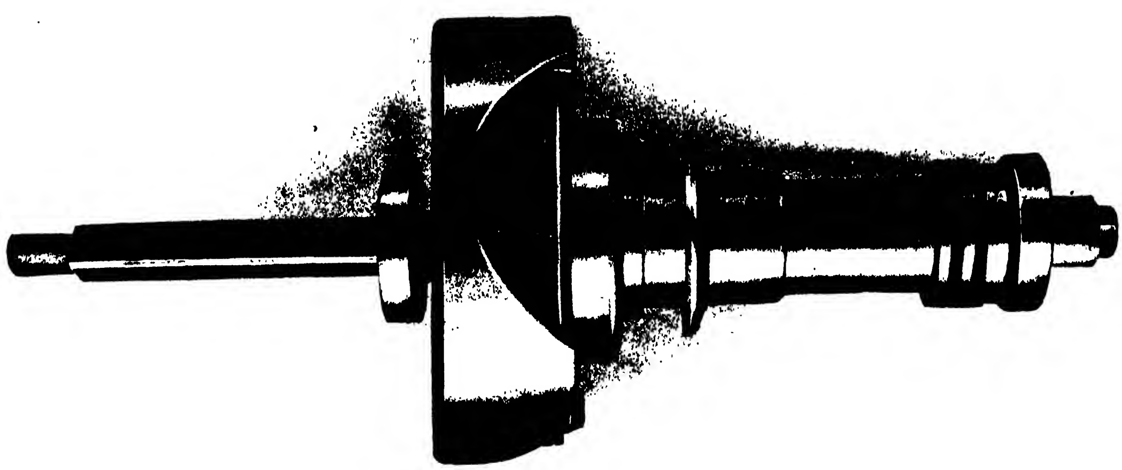


Fig. 454.—Speedwell Clutch

Another form of clutch, fig. 455, of an entirely different type, is used in the Mercedes car. It consists of a flat coil spring, wound loosely upon a steel drum, and anchored at one end to the boss of the flywheel, and at the other end to a rocking bell-crank

lever, which, when raised or lowered by means of the foot pedal, tightens or unwinds the spring upon the transmission-shaft drum. A spiral spring clutch of this description is very sensitive, and when properly adjusted gives excellent results.

Transmission Gear. The power developed in the engine is proportional to the total mean driving force at the crank, and to the revolutions per minute. Thus a given power may be the product of a small driving force and a high speed, or of a larger force at a correspondingly slower speed; and it is therefore possible to increase the driving force as desired, by suitably reducing the speed of the car, without in any way altering the actual power developed. When ascending a hill the required increase of driving force at the wheel rims can in this way be obtained if the necessary speed-change gearing is provided in the transmission. Provision must also be made for reversing the motion of the car, and this must be done in the gear box, as the engine cannot be run in the reverse direction.

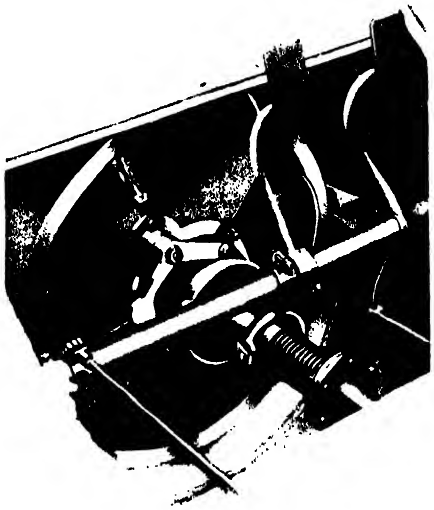


Fig. 455. Mercedes Clutch

A balance gear, or differential, must also be provided, to enable the two driving wheels to act independently when running round a curve, and yet to receive their motion from a common source. As the differential and the speed gears are frequently combined, the necessity for a balance gear will first be considered.

Balance or Differential Gear. When the steering wheels are so directed as to make the car run in a circular path, the outer driving wheel must necessarily travel over a greater circle than the inner, owing to their separation, which is considerable,

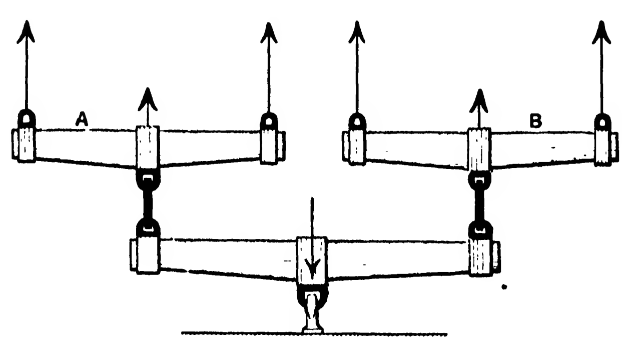


Fig. 456. Trace Bars analogous to the Differential Gear

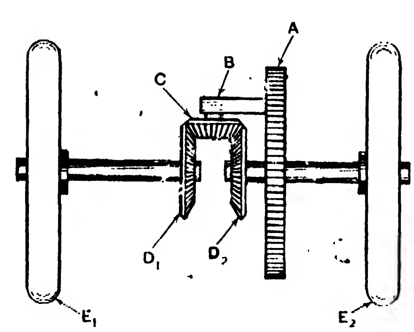


Fig. 457. Elements of the Differential Gear

and at the same time each wheel must be positively driven from the common transmission shaft. These conditions are satisfied by the differential gear, which is an arrangement of bevels analogous to the system of trace bars commonly used for combining the pulls of two horses, as shown in fig. 456. Any differences are thus combined, and the actual movement of the vehicle is at any instant the mean of the motions of the horses

at A and B. In the same way the motions of the wheels E_1, E_2, fig. 457, are combined by the bevels C, D_1, D_2, shown for clearness in their most elementary form. A is a wheel strung loosely on the wheel axle, and driven from the engine. A rigid arm B carries

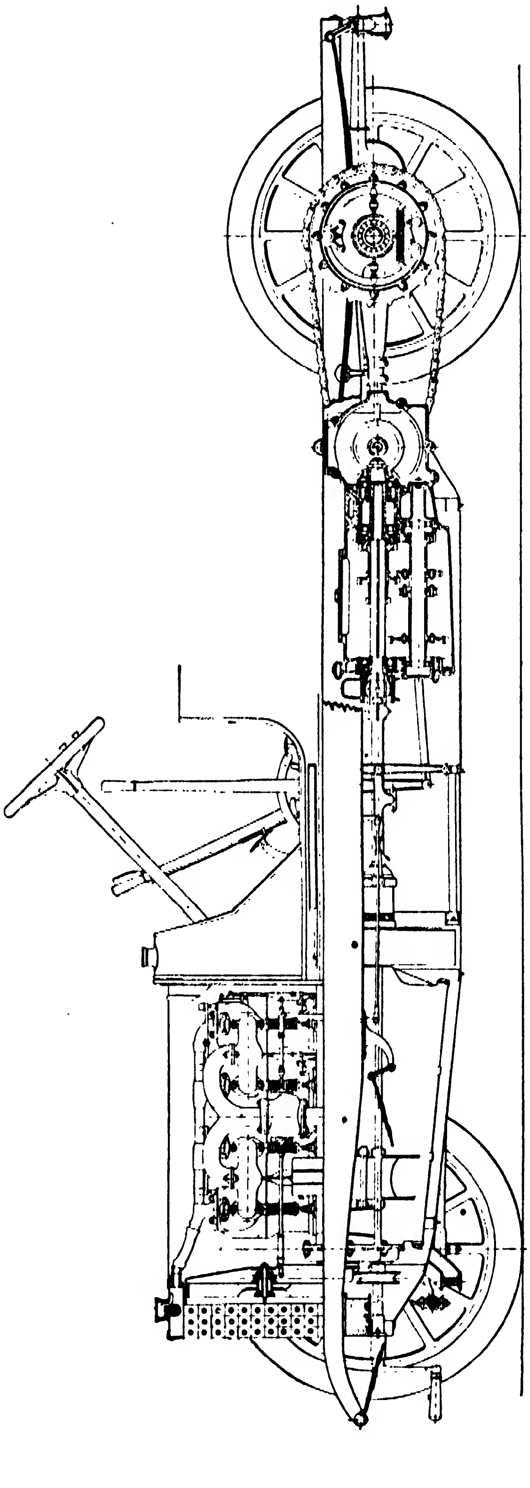


Fig. 458.—Side View of Chain-driven Chassis

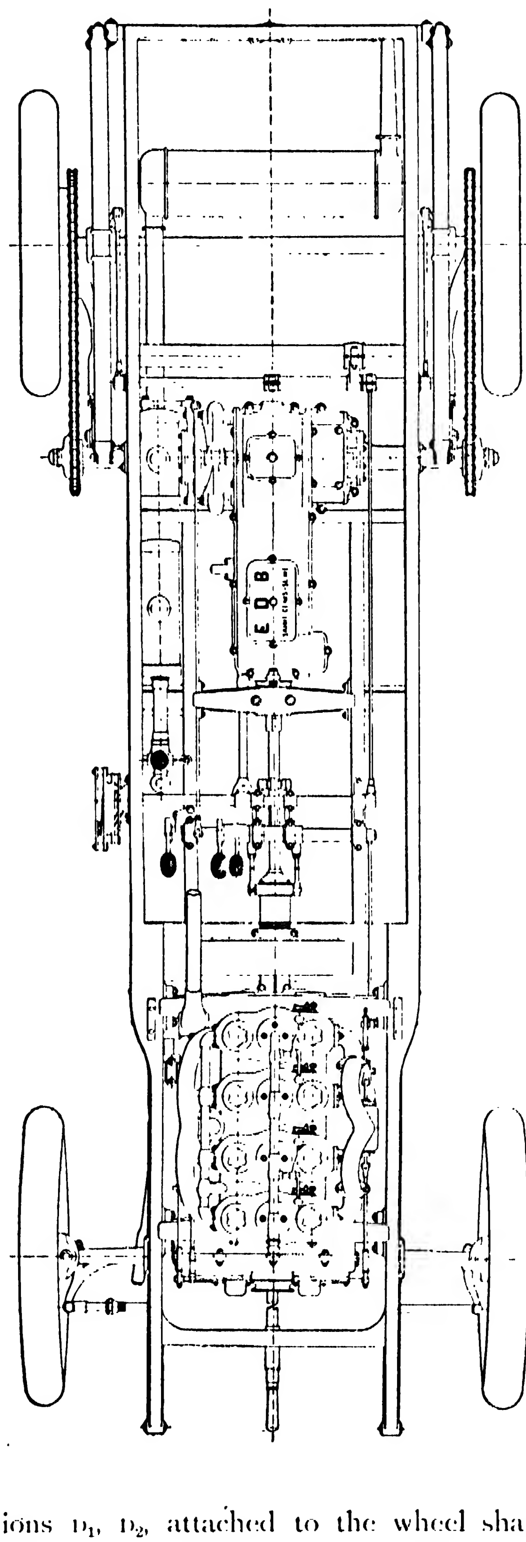


Fig. 459.—Plan of Chain-driven Chassis

the bevel wheel C, which gears with the pinions D_1, D_2, attached to the wheel shafts. If the steering wheels are so held as to keep the car running in a straight line, the driving wheels E_1, E_2, the differential gear D_1, D_2, C, and the wheel A will all be driven together as one by the engine, and the bevel C will not rotate on its spindle. If now

the steering wheels are turned and the car compelled to run round a curve, the outer wheel, say E_1, will rotate a little faster, and the inner wheel, E_2, a little slower than the transmission wheel A; and the bevel C will rotate by the necessary amount on its axis. The power may be transmitted to the driving wheels directly, as shown in figs. 460

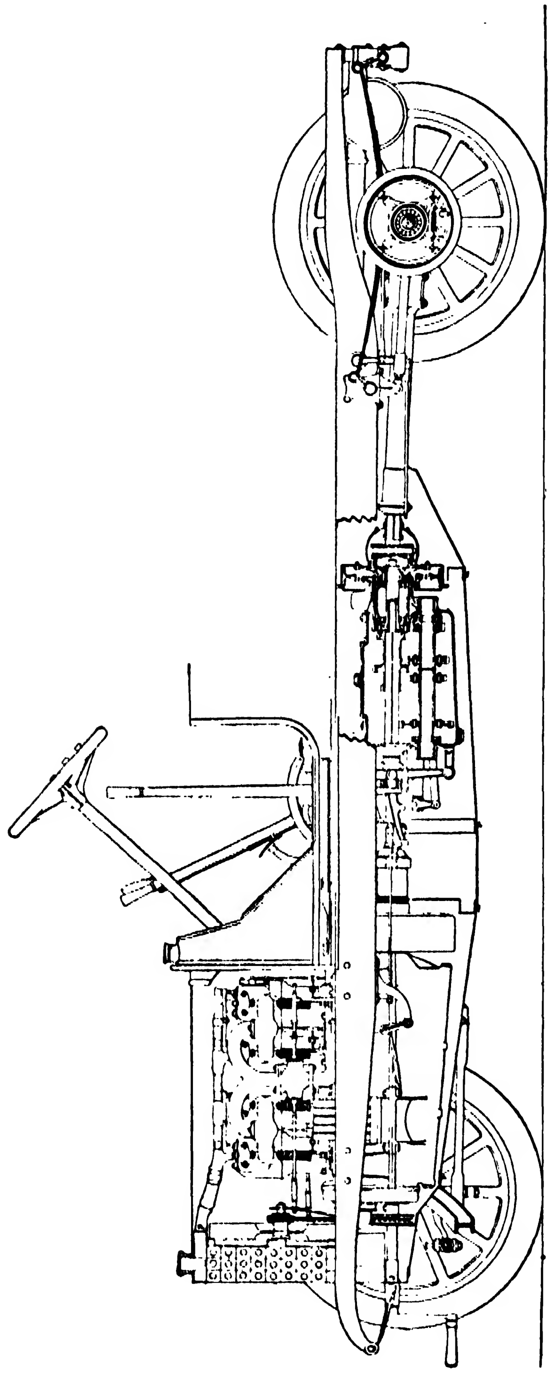


Fig. 460.—Side View of Chassis: Cardan-shaft System

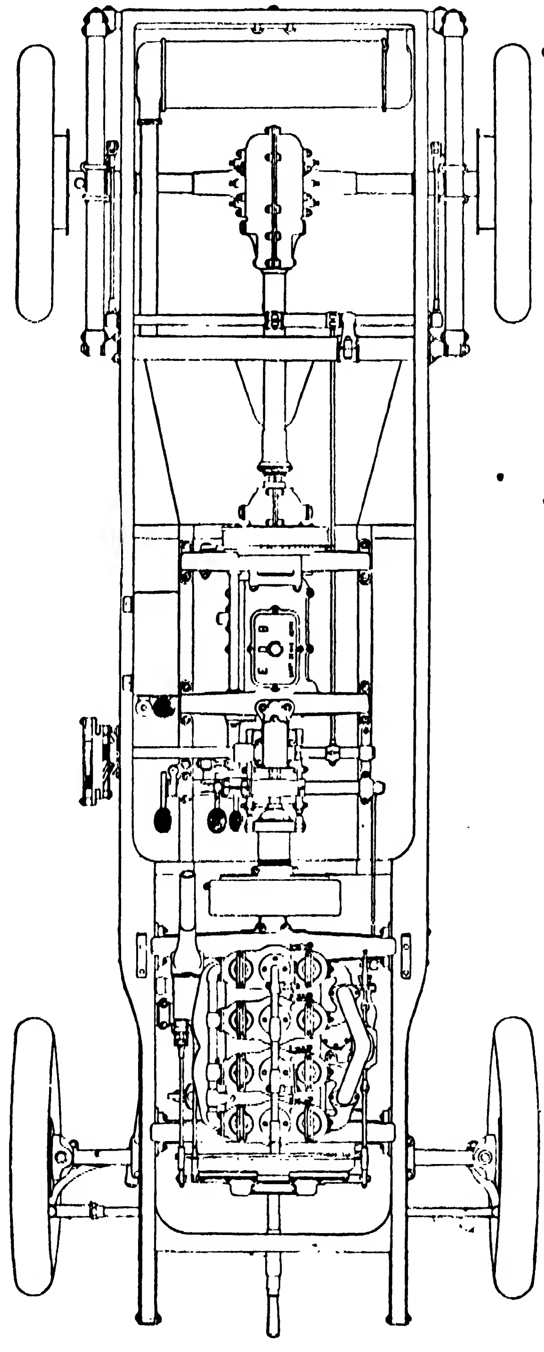


Fig. 461.—Plan of Chassis: Cardan-shaft System

and 461, which illustrate the Cardan-shaft or live-axle system; or by means of chains, as shown in figs. 458 and 459 of the same Delauney-Belleville chassis. Each system has features which are more or less favoured by different manufacturers. In the case of the chain-wheel drive the axle is continuous, and not so liable to break or bend; but as the chains are near the ground level the wear is considerable, unless precautions

are taken to exclude grit by entirely encasing them, as is sometimes done. The live axle, on the other hand, necessitates a division of the driving shaft, and the stresses upon it are more severe. To overcome this difficulty the wheels are generally mounted upon strong stationary hollow shafts, which take the whole weight, and the live axle has then to transmit the rotary motion only.

Speed Gears.—At the present time there is no positive mechanical gear which will provide for every speed variation, from the maximum determined by the running speed of the engine to zero, and the users of cars must therefore be contented with

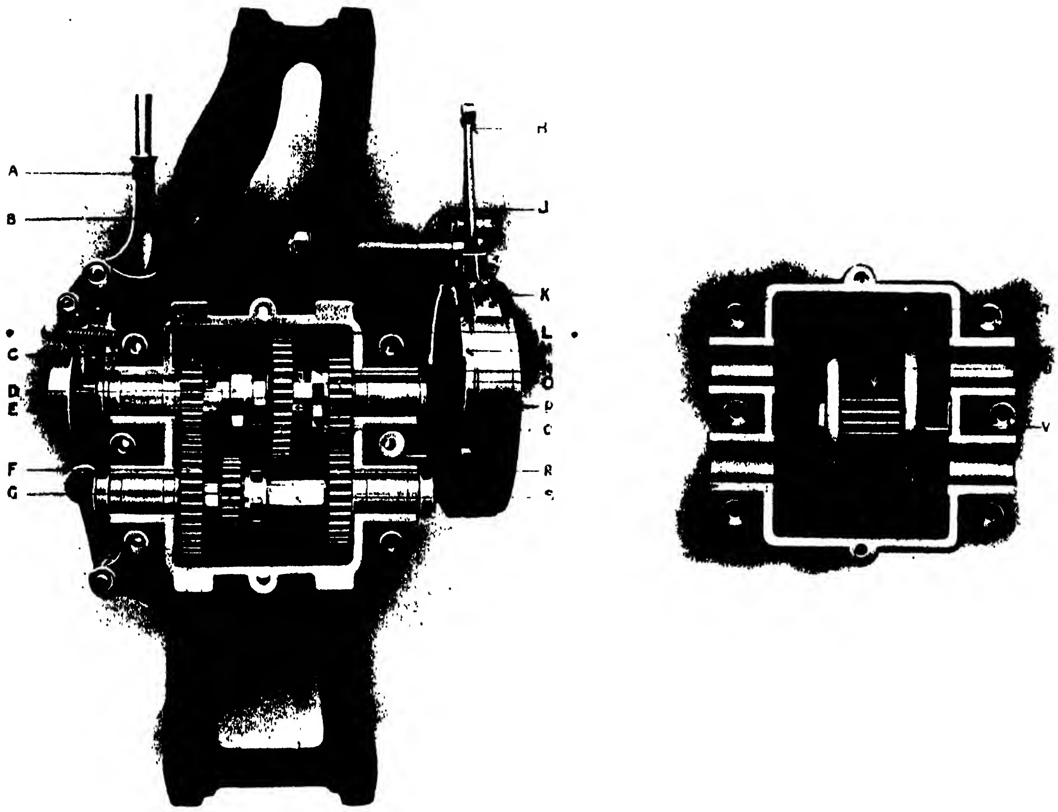


Fig. 462.—Argyll Three-speed Gear Box, showing Cover removed

two or more speed changes. Only cars of small powers are provided with but two forward speeds, and many makers always supply three, or, in the case of very large cars, four gears, in addition to a reverse gear provided for manœuvring the car. Fig. 462 shows the Argyll speed-gear box, which provides for three forward speeds and one reverse speed. Although the driving shaft appears to be continued through the box it is really not so, and the motion can only be transmitted by it through the pinions on the counter shaft S to the propeller shaft of the rear axle, excepting at the top speed, which is transmitted directly by coupling the shafts together, and by suitably disengaging the pinion driven from the counter shaft S. The driving shaft P acts directly through a universal coupling on the sliding wheel Q, which thus couples the driving shaft with the squared end of the main or propeller shaft. F is a spur wheel fixed to the counter shaft S, and is always in gear with C. As the pinion C is of smaller

diameter than the wheel F, the latter, and therefore also the shaft S, will rotate at a slower speed than the driving shaft. On the same shaft S is fixed the spur wheel K, gearing with the wheel O, which runs idly upon the propeller shaft. As the wheels K and O are of the same diameter, the wheel O will run at the same speed as the shaft S, and thus at a slower speed than the driving shaft. Between the wheels F and K the counter shaft is squared, and carries a pinion G, which always rotates with the shaft, and which can be moved along it by means of a forked lever engaging with the pinion collar. The end of the propeller shaft is also squared, and carries in a similar way the wheel Q, which is provided on both faces with clutches D and L. It is this wheel Q which actually drives the propeller shaft, and the various speeds must be transmitted through it. When the wheels are arranged as shown in the figure, with the wheel Q

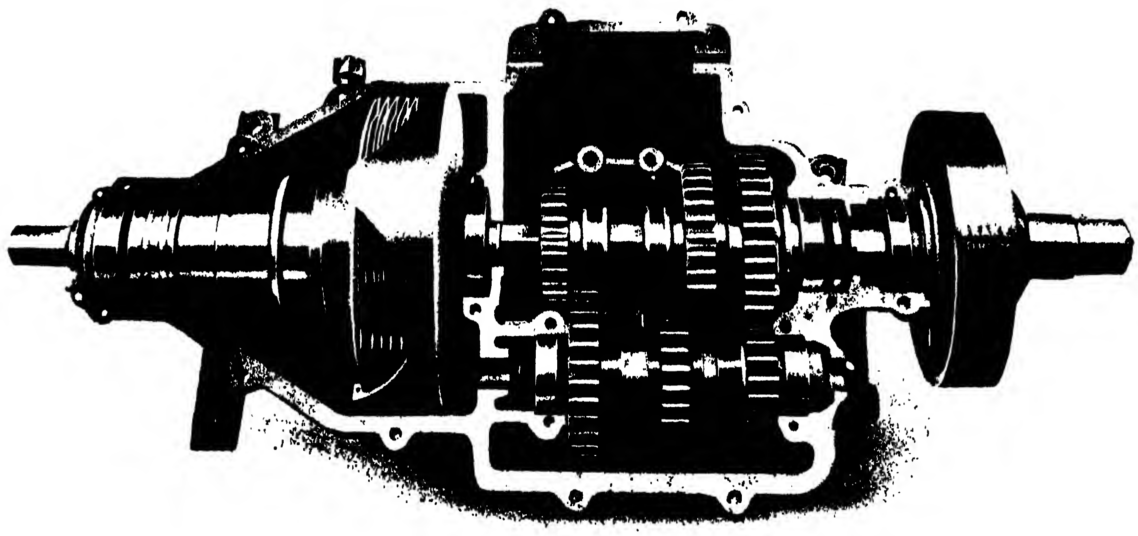


Fig. 463.—Speedwell Gear Box, for one reverse and three forward speeds

in its mid position, clear of the clutches E and N, the motion of the driving shaft is not transmitted to the propeller shaft, as the wheel O runs idly upon it; that is to say, the car remains stationary while the engine works as usual. For the third or top speed the wheel Q is moved towards the left by means of the lever A, until its clutch face engages with the clutch E, and the drive of the shaft is then directly transmitted. It is desirable to have a direct drive, without the use of the intermediate gears, for the speed at which the car is intended most frequently to run at. It will be noted that the counter shaft S and the wheel O run idly during this third speed.

The second speed is obtained by moving the wheel Q to the extreme right, until the clutch face L of the wheel engages with the clutch N, and disengages with E. In this position the drive is transmitted from C through the counter shaft S to the wheel O, and thus through the clutch to the wheel Q on the propeller shaft, which then rotates at a slower speed as already explained. To obtain the first or slowest speed Q must be replaced in its mid position, clear of the clutches E and N, and the pinion G must then be moved along the counter shaft into gear with Q. As before, O rotates idly while the drive is transmitted through the reducing gears C, F, and G, Q. To

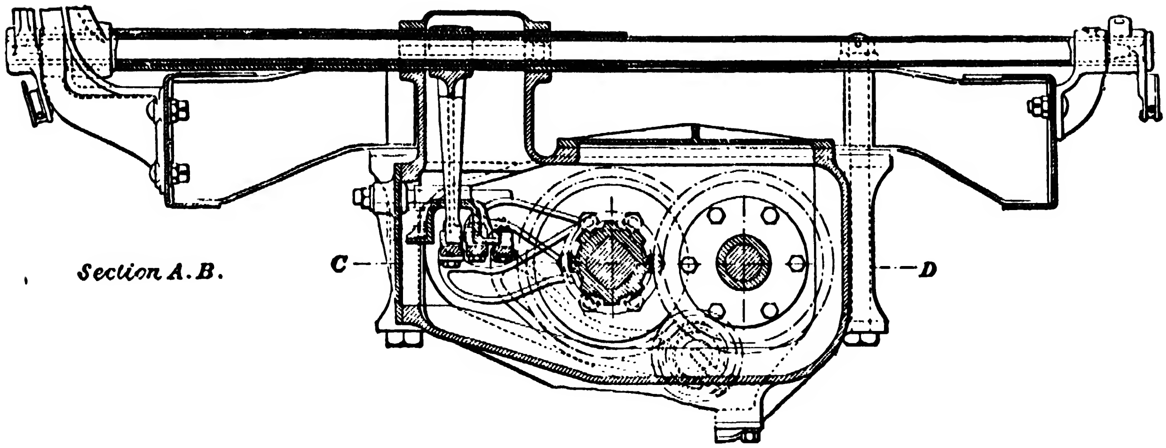


Fig. 464. Siddeley Gear Box. Sectional End Elevation

reverse the motion it is necessary to introduce into the train of wheels an additional one, which in this particular design is carried eccentrically upon the box cover, as shown at U. The pinion is wide enough to gear with Q and G when these are not in mesh, and it may be swung down into gear by suitably rotating the eccentric spindle V upon

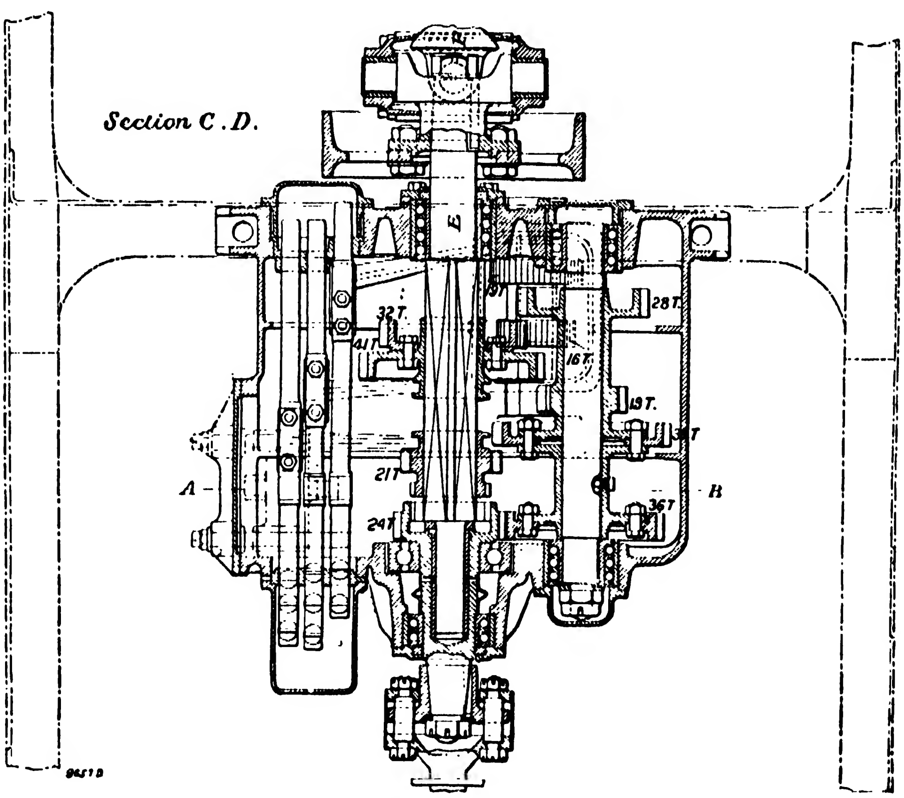


Fig. 465. Siddeley Gear Box. Sectional Plan

which it revolves. The drive then takes place through C, F, and G, and through the reversing pinion U to the wheel Q and the main propeller shaft.

A similar type of gear box providing three forward speeds and one reverse is illustrated in fig. 463. It is the arrangement used in the Speedwell car, a notable feature of which is the inclusion in the gear casing of the corrugated disc friction

clutch. The clutch as well as the gearing runs in oil, and the wear is thus reduced to a minimum.

The Siddeley gear box of the Wolseley Tool Company is illustrated in figs. 464, 465, 466, and 467, which show the details of the construction. Fig. 464 is a sectional

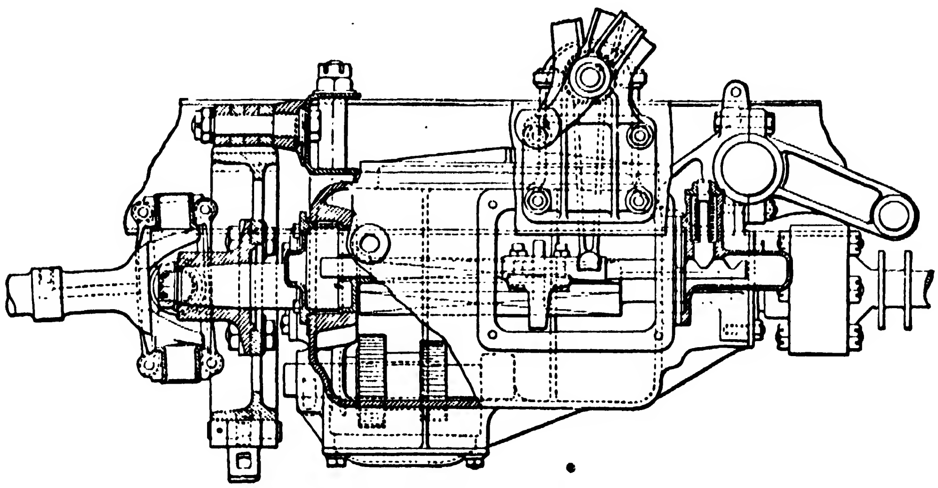


Fig. 466.—Siddeley Gear Box. Side View

end view through A B, showing the arrangement of striking rods, and fig. 465 is a sectional plan through the gears. Fig. 466 is a side view in partial section, and fig. 467 an end view showing the strap brake in position. In this arrangement the wheels upon the counter shaft are fixed to it, and the various forward and reverse

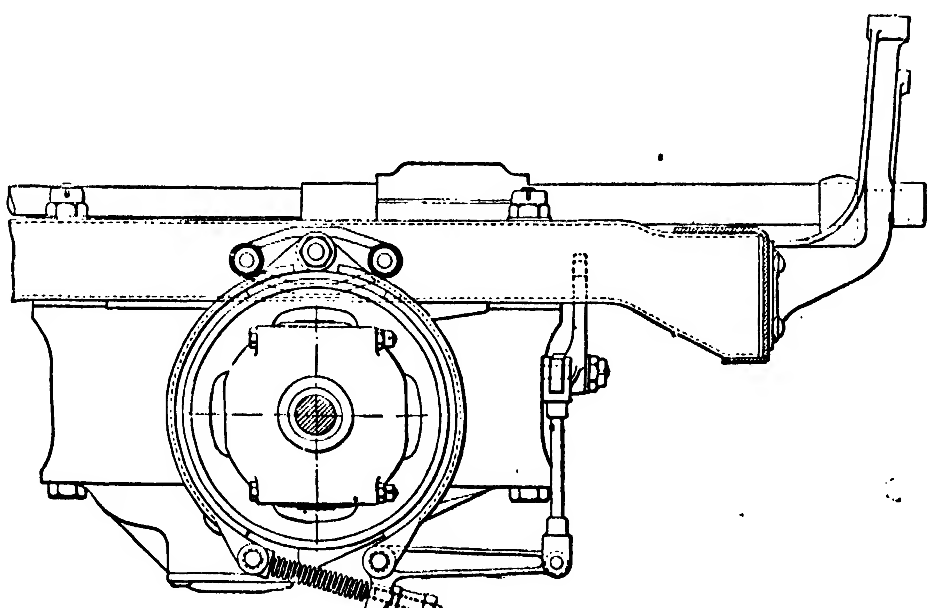


Fig. 467.—Siddeley Gear Box and Shaft Brake

speeds are obtained by altering the positions of the spur wheels on the squared portion of the propeller shaft. At the left side of fig. 465 are shown the three striking rods which control the positions of the gears, and a feature of the arrangement is the interlocking system, which prevents their simultaneous operation. The method of bearing

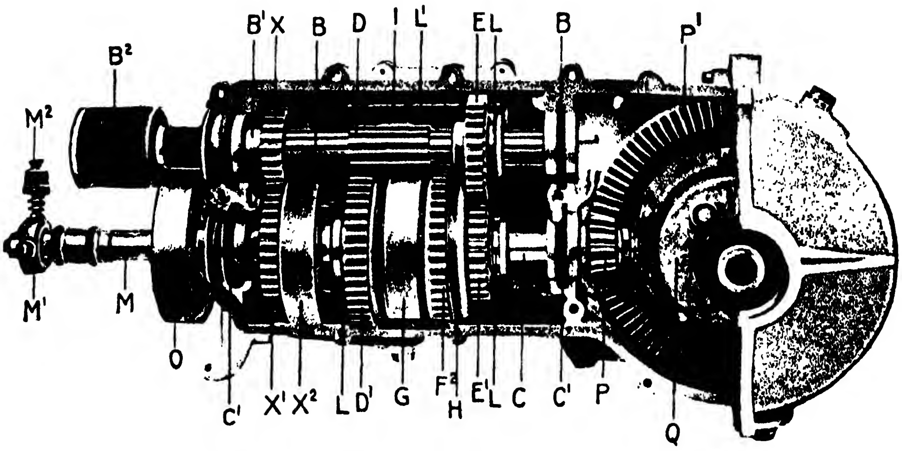


Fig. 468. Internal-Clutch Change-speed Gear Box (De Dion-Bouton)

the extreme end of the propeller shaft in the hollow driving shaft is also clearly shown in fig. 465.

Some care is necessary when changing from one gear to another to prevent a jarring shock as the teeth come into mesh, and even experienced drivers occasionally

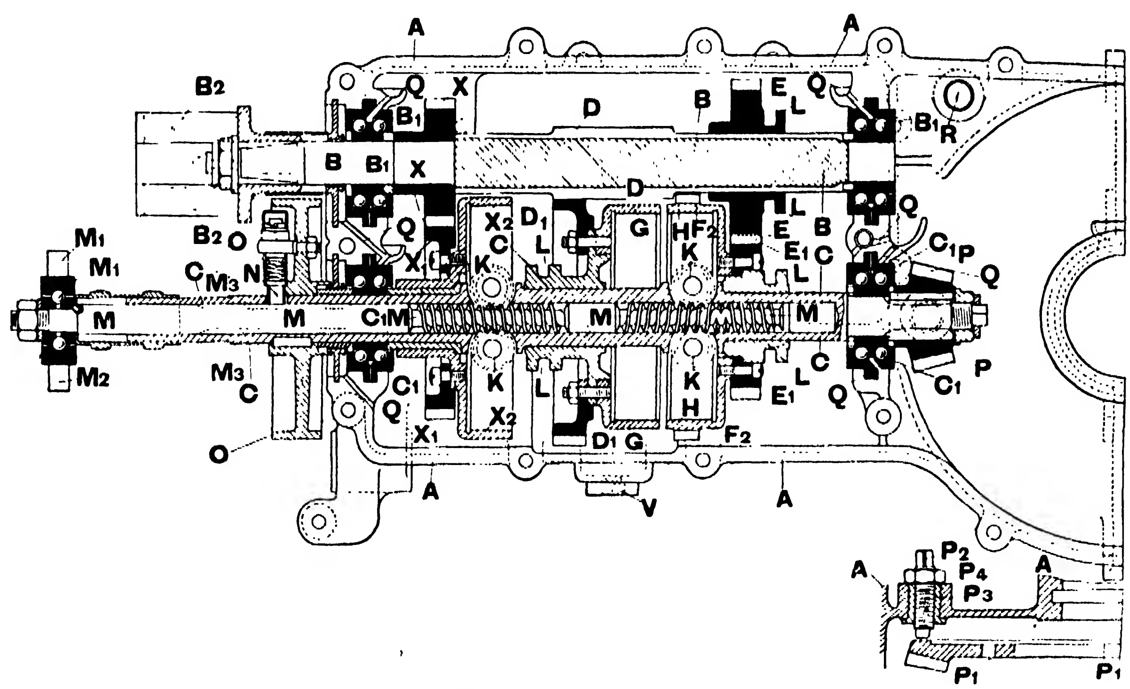


Fig. 469.—Section of Gear Box (De Dion-Bouton)

fail to do so. By tapering the edges of the teeth, and by similar devices, the difficulty is to some extent reduced.

In the De Dion expanding clutch arrangement this objection is entirely overcome, as the gears remain always in mesh and the changes are made by expanding one or other of the internal clutches, which are shown at X^2, G, and H, fig. 468, and in section in fig. 469.

B^2 is the engine shaft from which when the clutches are operated the motion is communicated to the shaft M and through the bevel gears P and P^1 to the propeller shaft.

By means of a horizontal lever placed conveniently at the controlling wheel the clutch arms within the drums X^2, G, and H can be expanded so as to connect one or other of the drums to the shaft M.

In the declutched position all the drums, with the wheels X^1, D^1, and E^1 attached to them, run idly upon the shaft and no motion is therefore transmitted to the main propeller shaft.

It will be seen that the ratios of the three pairs of wheels $X X^1$, $D D^1$, and $E E^1$ are

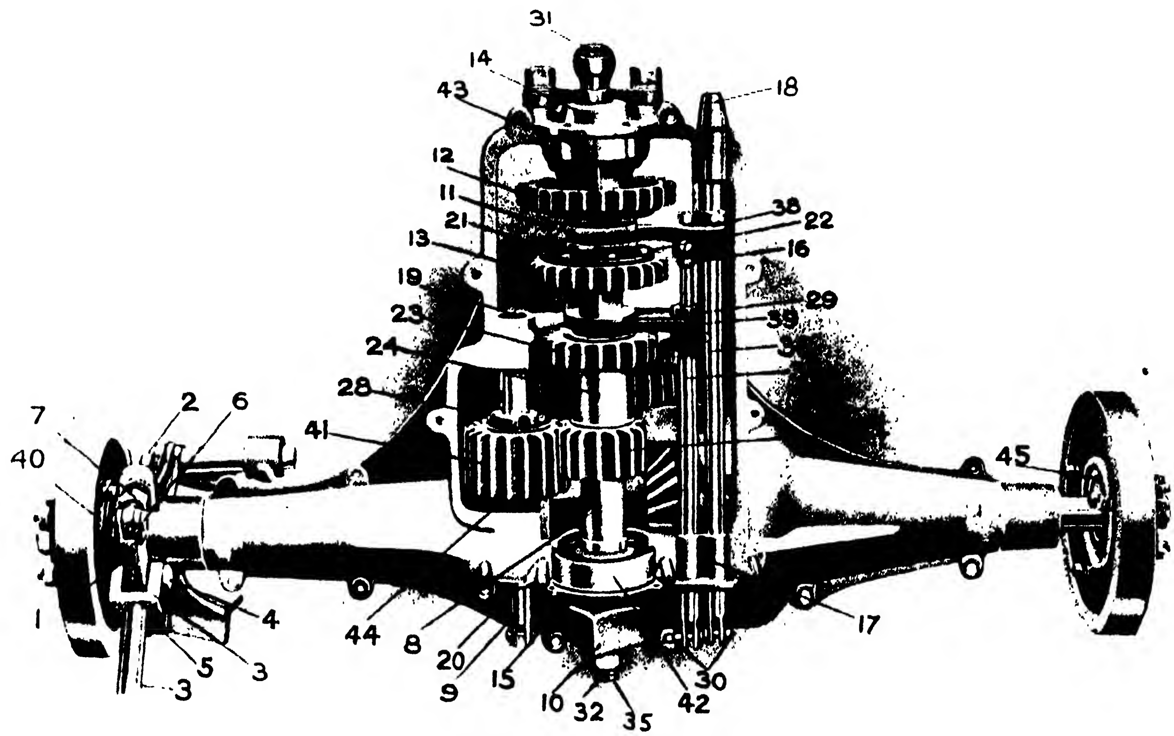


Fig. 470. Daimler Gear Case View as seen from above

1. Radius-rod link.
2. Adjusting rod.
3. { Radius rod end. / Tube for radius-rod end.
4. Pins for radius rod ends.
5. Bolts for radius-rod link.
6. Joint pin for adjusting rod.
7. Nut for adjusting rod.
8. Driving shaft.
9. Reverse shaft.
10. Square on driving shaft.
11. Loose sleeve on driving shaft.
12. Fourth-speed gear on driving shaft.
13. Third-speed gear on driving shaft.
14. Cover for driving-shaft bearing.
15. Oil cover for driving shaft.
16. Bush for striking fork.
17. Bearing for striking fork
18. Bearing lining for striking shaft.
19. Reverse shaft bush.
20. Reverse-shaft bush.
21. Bolts for third- and fourth-speed gears on driving shaft.
22. Thin nuts for ditto.
23. Second speed on driving shaft.
24. First speed-gear sleeve on driving shaft.
28. Nut for reverse shaft.
29. Nuts for striking fork (slotted).
30. Joint pins for striking fork.
31. Joint bolt for suspension bolt.
32. Nut for outer end of driving shaft.
35. Spring for outer end of driving shaft.
36. Long-striking fork rod.
37. Short-striking fork rod.
38. Striking fork.
39. Striking fork.
40. Oil rings for brake drums.
41. Reversing pinion.
42. Ballrace for driving shaft (front end).
43. Ballrace for driving shaft (rear end).
44. Ballrace for reversing pinion.
45. Ballrace for cross-shaft ends.

different, and that the shaft M will rotate at different speeds accordingly as one or other of the gears is in the clutched position.

E and E^1 form the high gears, X and X^1 are the middle gears, and D and D^1 are the low-gear wheels, and to change from one gear to another it is necessary to bring the desired clutch into operation by means of the controlling lever.

While one drum is clutched to the shaft the others are free and rotate idly.

Before, however, the low gear $D D^1$ can be brought into operation it is necessary

to move all the parts on the shaft M between the collars L L, together with the wheel F, bodily towards the right until the drum G comes over the clutch at K, when the gears may be clutched to the shaft as before.

For the reverse speed it is necessary first to disengage the wheel E by moving it alone towards the right, and then to bring into gear an intermediate pinion between the wheels F^2 and D, which it will be seen do not gear directly.

By clutching the drum H the motion of the engine shaft is then transmitted from D through the intermediate pinion to the wheel F^2 and thus to the shaft M.

Live Axle Gear.—Some explanation has already been given of the function of the differential, and it only remains to describe its application in the two cases

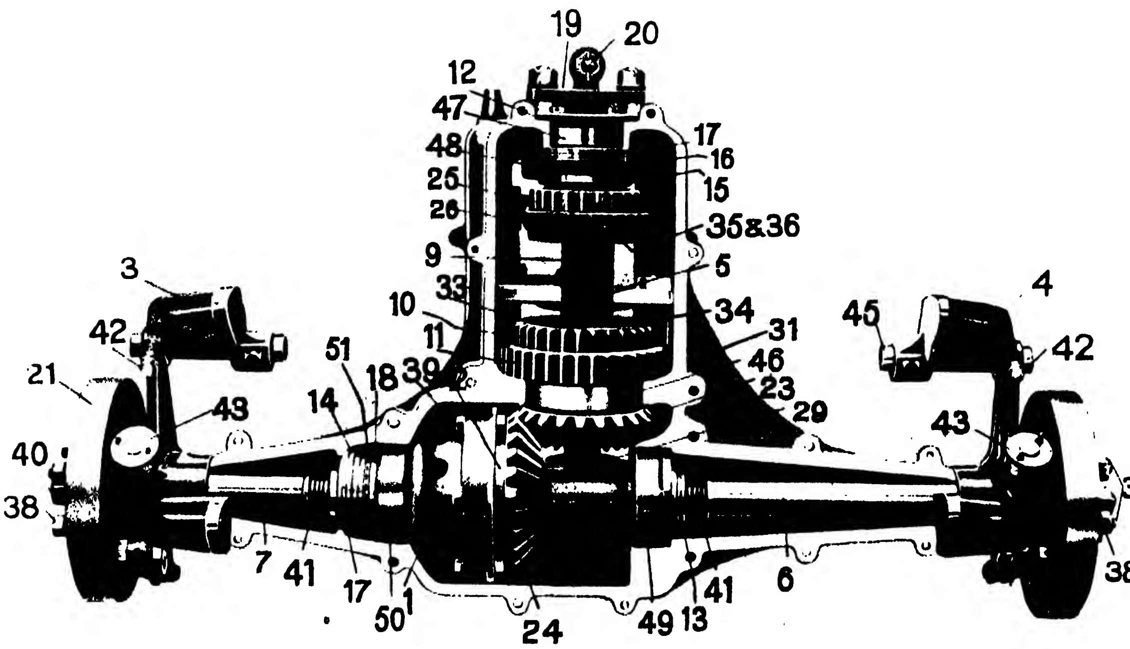


Fig. 471.—Daimler Gear Case. View as seen from below

illustrated in figs. 458, 459, 460, and 461. Referring to these figures, it will be seen that in the one case (figs. 460, 461) the drive is transmitted directly from the speed-gear box through what is technically known as a Cardan shaft to the differential gear upon the rear or live axle. With the chain drive shown in figs. 458 and 459 the differential gear is arranged on a shaft which passes transversely through the rear of the speed-gear box, and which carries at its ends the chain-driving sprockets.

This latter arrangement of speed gears and differential is illustrated in considerable detail in figs. 470 and 471 of the Daimler transmission, which need not be further described here.

The live-axle arrangement, as applied to the Argyll car, is illustrated in fig. 472, which shows the whole arrangement from the brake drum D_1, immediately behind the speed-gear box, through the flexible couplings and the Cardan shaft to the differential gear on the two halves of the driving-wheel axle D, D. D_1 is the brake drum on the

propeller shaft, and C_1 is the Cardan or driving shaft, provided at either end with flexible couplings A_1, A_1, of the Hooke type to ensure sufficient flexibility. A pinion O on the end of the shaft Q gears with the large driving bevel, to which is rigidly attached the differential-gear casing M. On spindles J, projecting within this casing, are carried the differential jockey pinions I, two of which are used as shown to preserve the balance of the revolving parts. L, L are the differential wheels fixed to the two

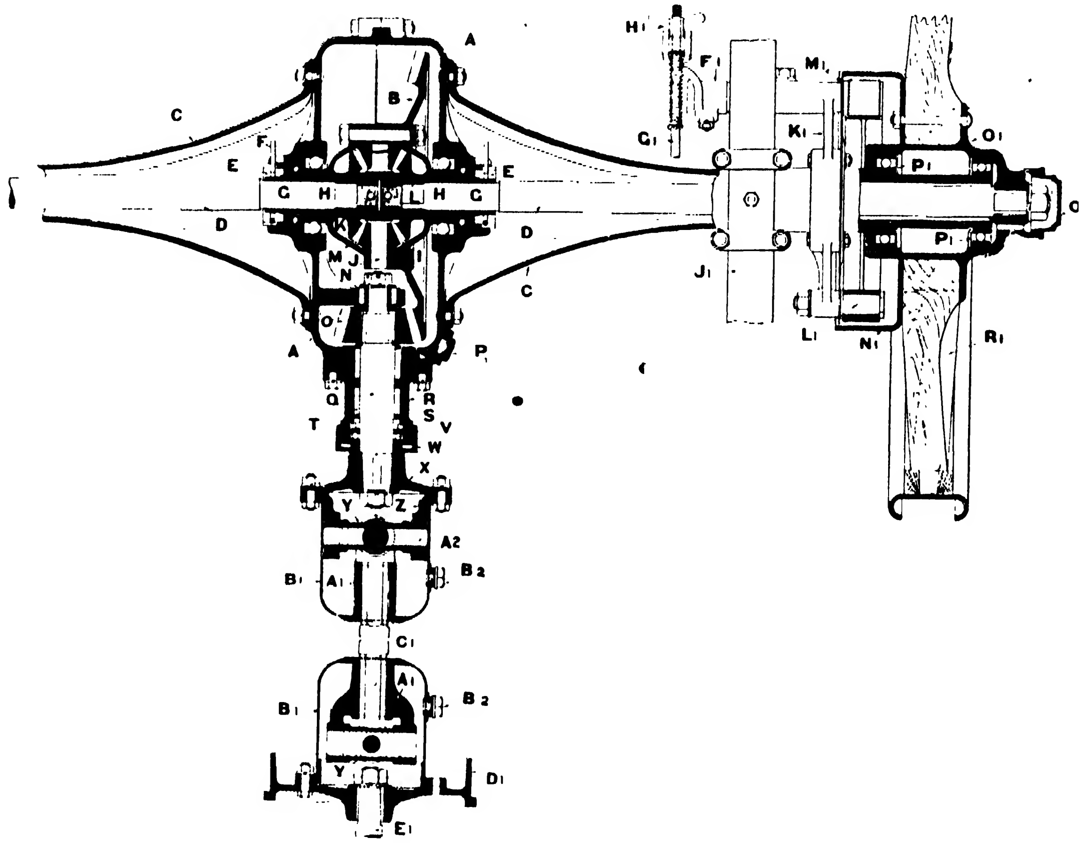


Fig. 472.—Argyll Car Back Axle

A. Driving gear casing.
B. Driven bevel wheel.
C. Cone casing.
D. Axle shaft.
E. Ball-thrust adjusting ring.
F. Ball race adjusting-ring lock.
G. End-thrust ball race.
H. Inner ball race.
I. Differential pinion.
J. Differential crosshead.
K. Axle-lock nut.
L. Axle differential wheels.
M. Differential casing.
N. Tail-shaft bottom bush.
O. Driving pinion.
P. Inspection plug.
Q. Pinion spindle.
R. Spindle bearing casing.
S. Spindle-roller bearing, outer sleeve.
T. Spindle-roller bearing, inner sleeve.
V. Bevel pinion-thrust bearing.
W. Pinion-adjusting column.
X. Flange for universal joint.
Y. Universal crosshead.
Z. Universal joint, main fork.
A_1. Universal fork.
B_1. Joint casing.
B_2. Plug for grease injector.
C_1. Propeller shaft.
D_1. Brake drum.
E_1. Gear box, main shaft.
F_1. Brake actuating lever.
G_1. Brake connecting rod.
H_1. Brake-adjusting thumb screw.
J_1. Spring.
K_1. Hand-brake bracket.
L_1. Hand-brake fulcrum pin.
M_1. Dust shield.
N_1. Brake drum.
O_1. Hub flange.
P_1. Wheel ball race.
Q_1. Axle cap.
R_1. Road wheel.

halves of the wheel axle D, and driven directly from B through the differential pinions. Although the road wheels R_1 with their brake drums N_1 are driven from the axles D, D, the weight is carried to a great extent upon the strong and rigid casing A, C, which encloses the whole of the mechanism. The live portion of the axle runs in solidified oil, which ensures continuous lubrication of the moving parts.

Two sets of brakes are generally provided, one upon the brake drum immediately behind the speed-gear box at D_1, fig. 472, operated from a foot pedal, and one upon each of the wheels actuated simultaneously from a hand lever.

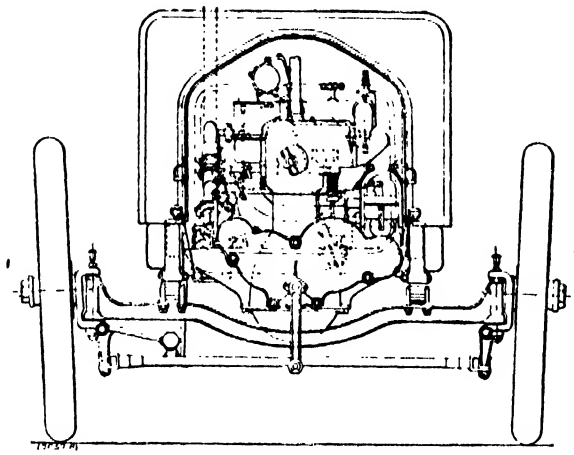


Fig. 473.—Front View of Siddeley Chassis

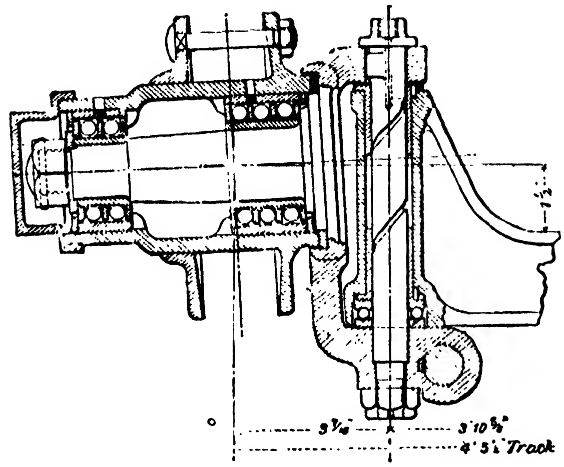


Fig. 474. Hub and Swivel for Front Axle

Steering Gear. As the actual driving of the car is transmitted through the road wheels on the rear axle, the steering of the car is done at the front wheels. In horse-drawn vehicles it is sufficient for the purpose to turn the front axle about a pivot midway between the wheels, but this is not practicable in the case of the

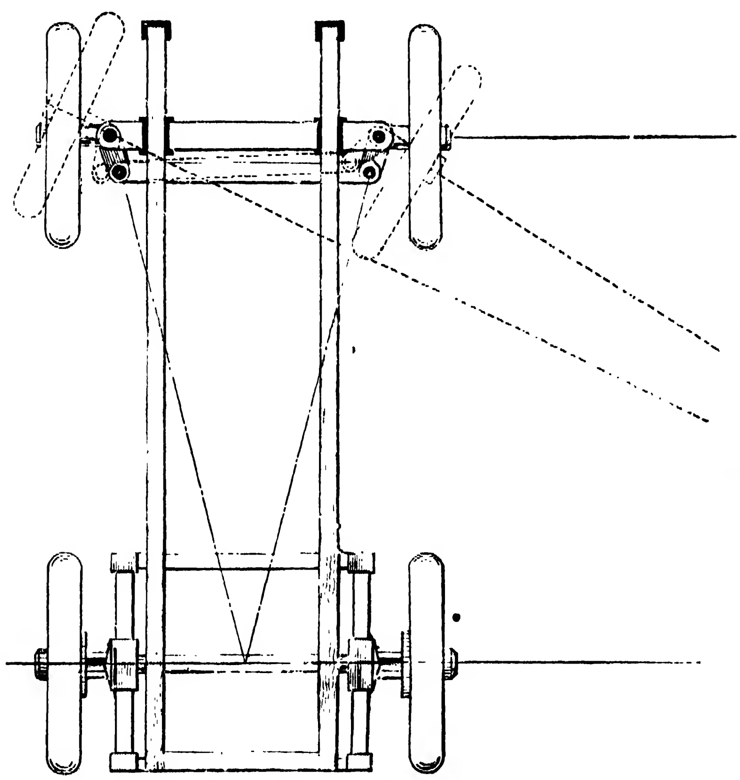


Fig. 475.—Diagram of Steering Arrangements, Ackermann System

Fig. 476. Steering-wheel Worm and Sector

heavier and faster motor-car vehicle, as the leverage of the wheels about the centre of the axle would make steering very difficult and irregular whenever small obstructions were met by one or other of the front road wheels. There are the further objections that the stability of the car would be seriously affected if the axle were turned through the considerable angles necessary for the turning of such long

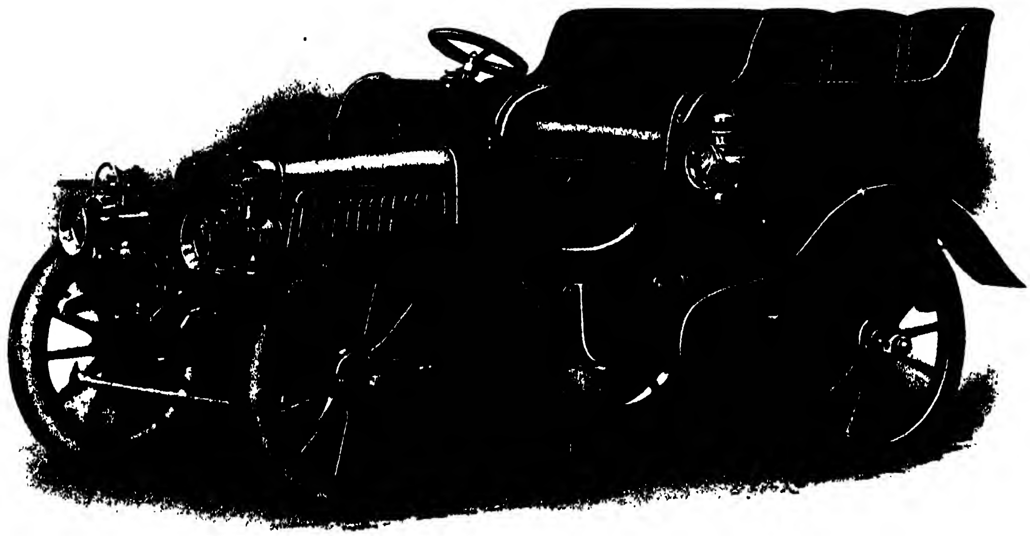


Fig. 477. Albion 16-H.P. Standard Tonneau

vehicles, and the axle would require to be very strong to carry the weight of the car and to withstand the shocks applied at its middle.

These objections are satisfactorily overcome by carrying the front wheels upon stud axles, pivoted in a vertical plane, or nearly so, to the main axle, the position of

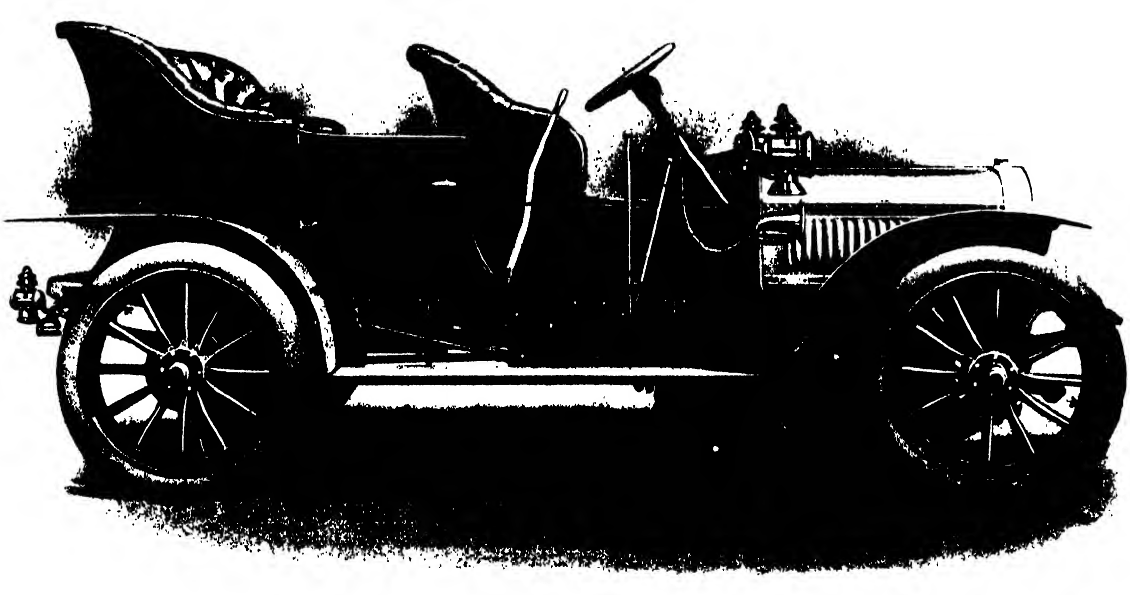


Fig. 478.—12–14-H.P. Argyll Car (Four-cylinder), Side-entrance Carriage

which is not altered. Fig. 473 shows a front view of a car with the front wheels separately pivoted, and coupled together by a transverse coupling; and fig. 474 is a section through one of the hubs, showing the arrangement of the stud axle and the pivot. It is necessary that the wheels should be tangential to the curve round which

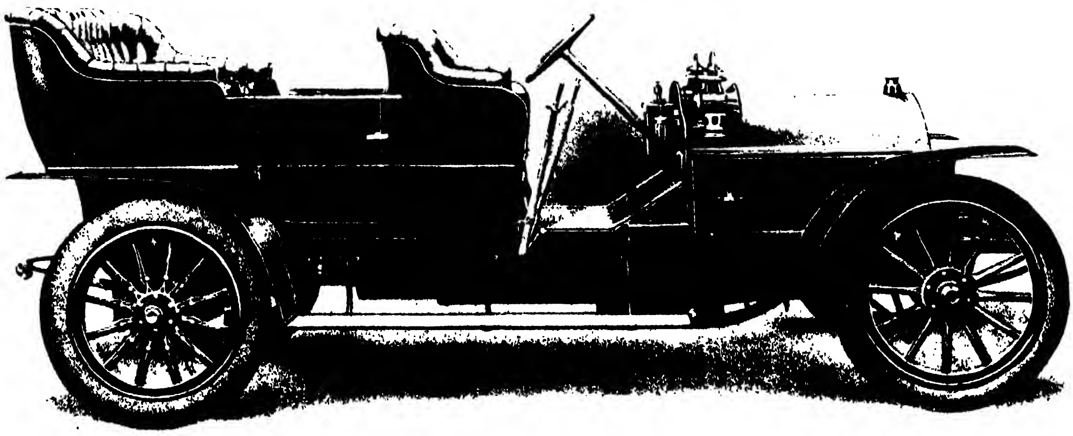


Fig. 479.—20-28-H.P. Darracq Car

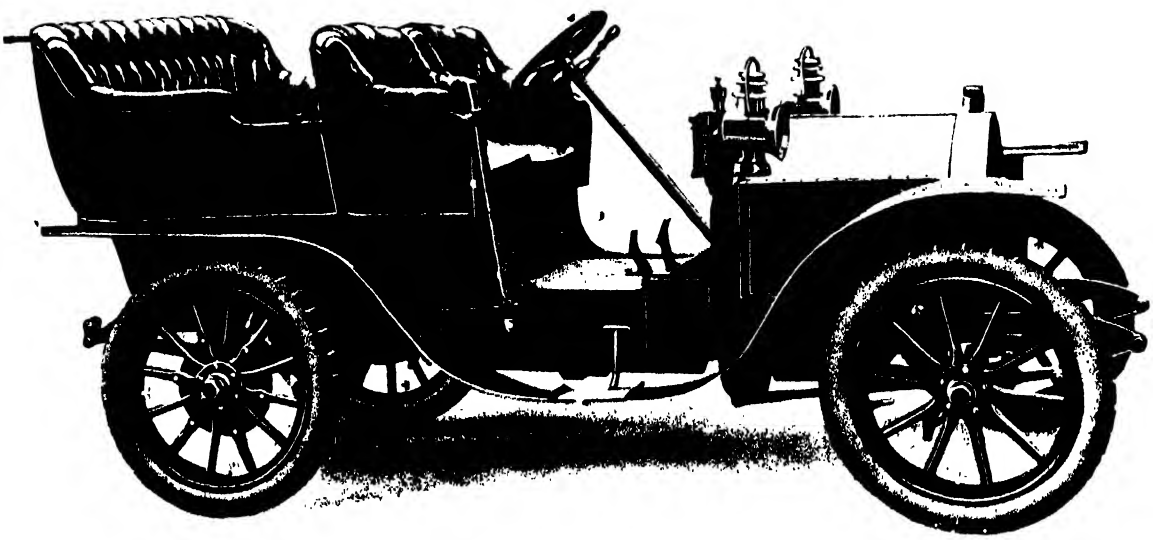


Fig. 480.—10-12-H.P. Darracq, with Phaeton Body and front entrance to Tonneau

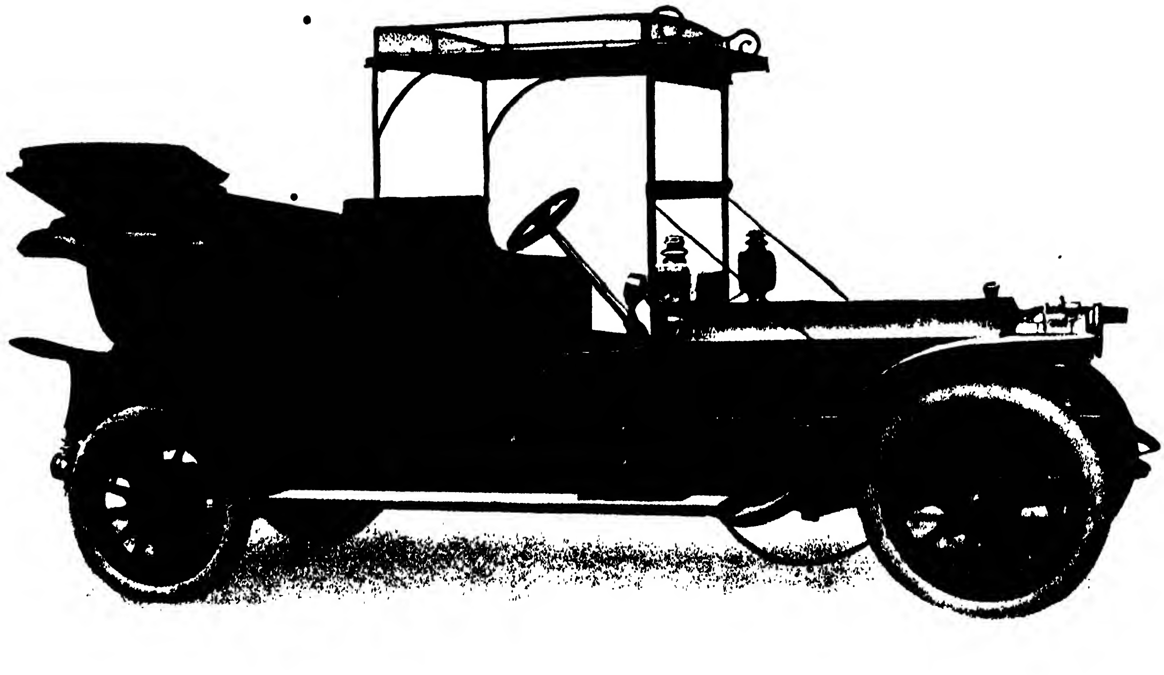


Fig. 481.—Rolls-Royce 40-50-H.P. Six-cylinder Single Landaulette

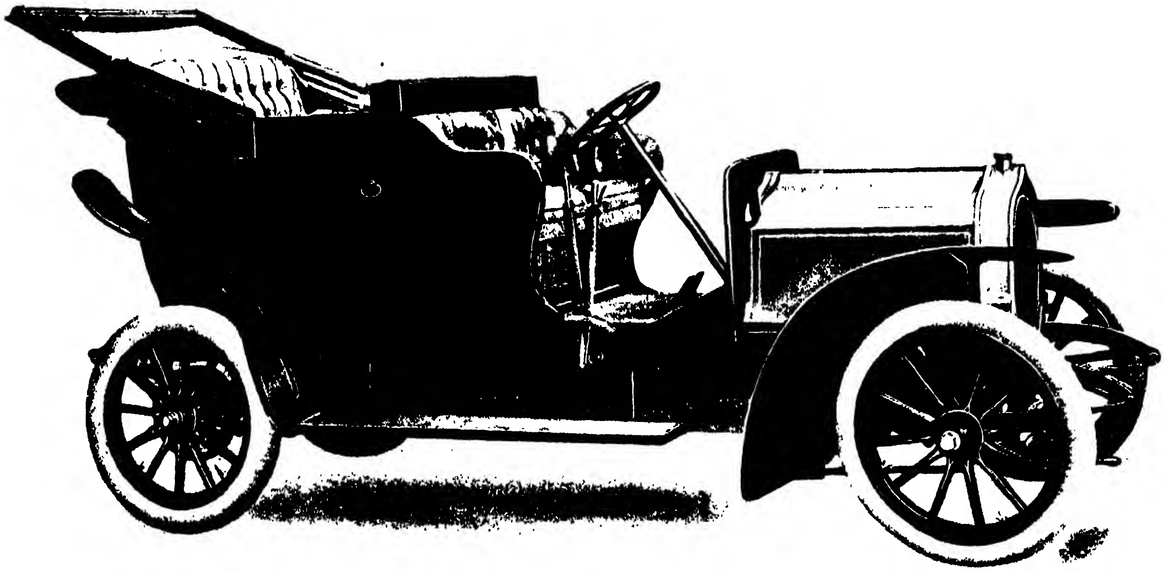


Fig. 482.—25-H.P. Speedwell Car, with Landaulette Body

the car is running, in order to avoid lateral dragging and wearing of the tyres, and to satisfy this condition the wheels must be turned through different angles, as is indicated in the diagram fig. 475, which shows what is known as the Ackermann system. The arrangement is such that the centre of the curve over which the car is passing lies

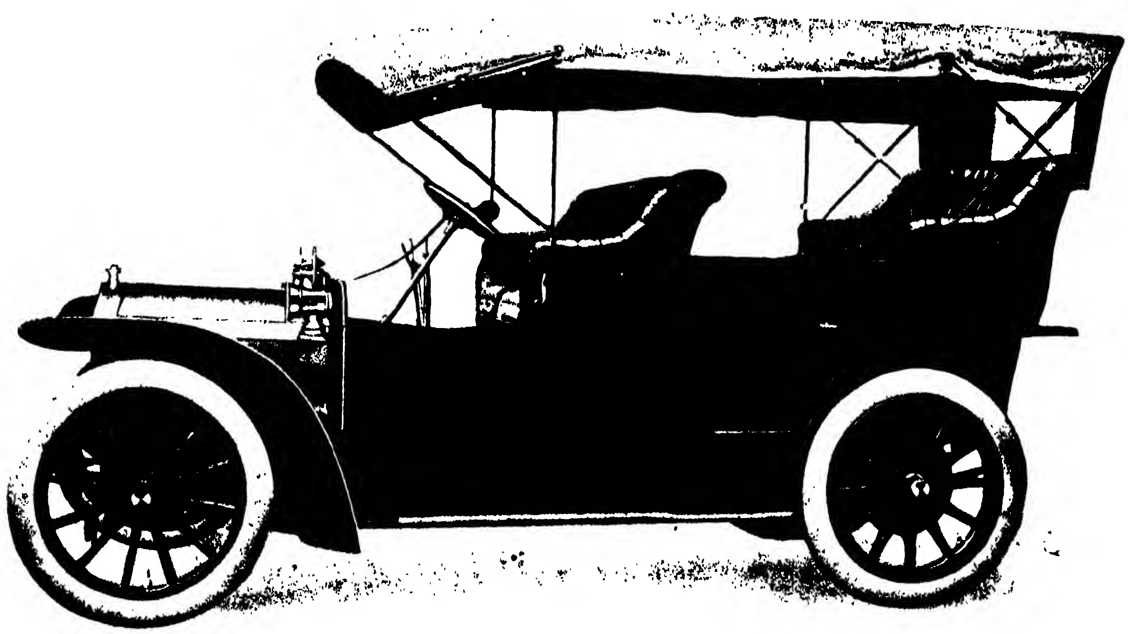


Fig. 483.—Cape-cart Cover

upon the continuation of the rear axle, so that the rear driving wheels are always tangential to the curve. For the front wheels the axle arms are so directed as to intersect if prolonged at the middle of the rear axle when the car is moving straight forward. If, then, the arms are coupled together, and the wheels turned, the directions

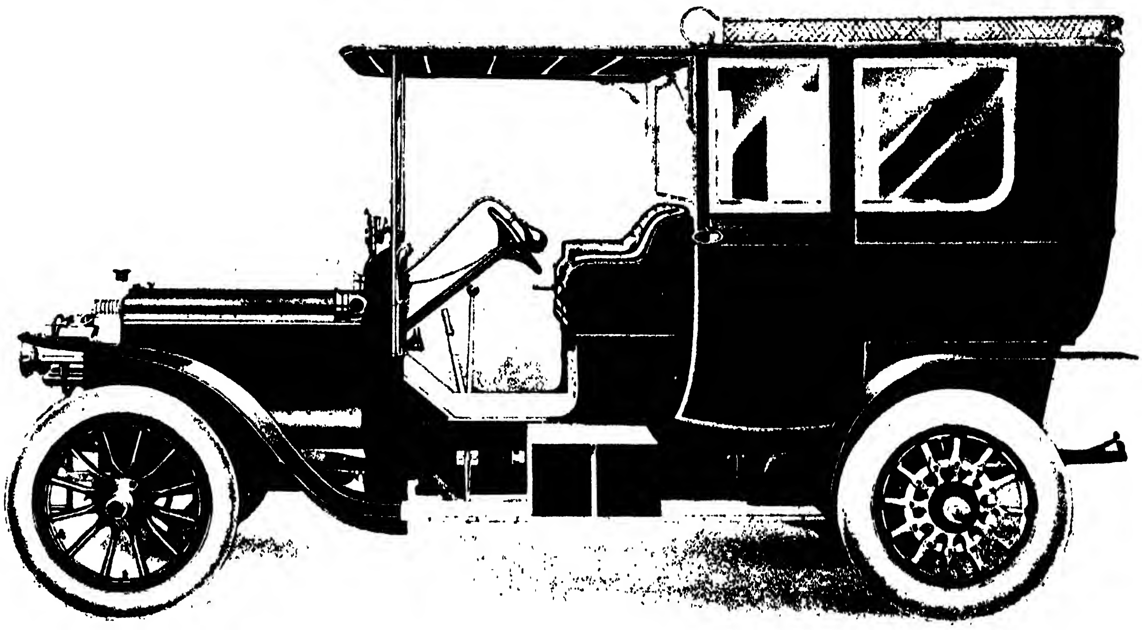


Fig. 484. Five-to-Seven-seated Daimler Limousine Car

of the arms should again intersect on the prolongation of the rear axle. Even with this arrangement of short stud axles it is desirable that any shock at the road wheels, however slight, should not be felt at the steering wheel, and that there should be no possibility of the latter being jerked from the control of the driver. Some type of irreversible

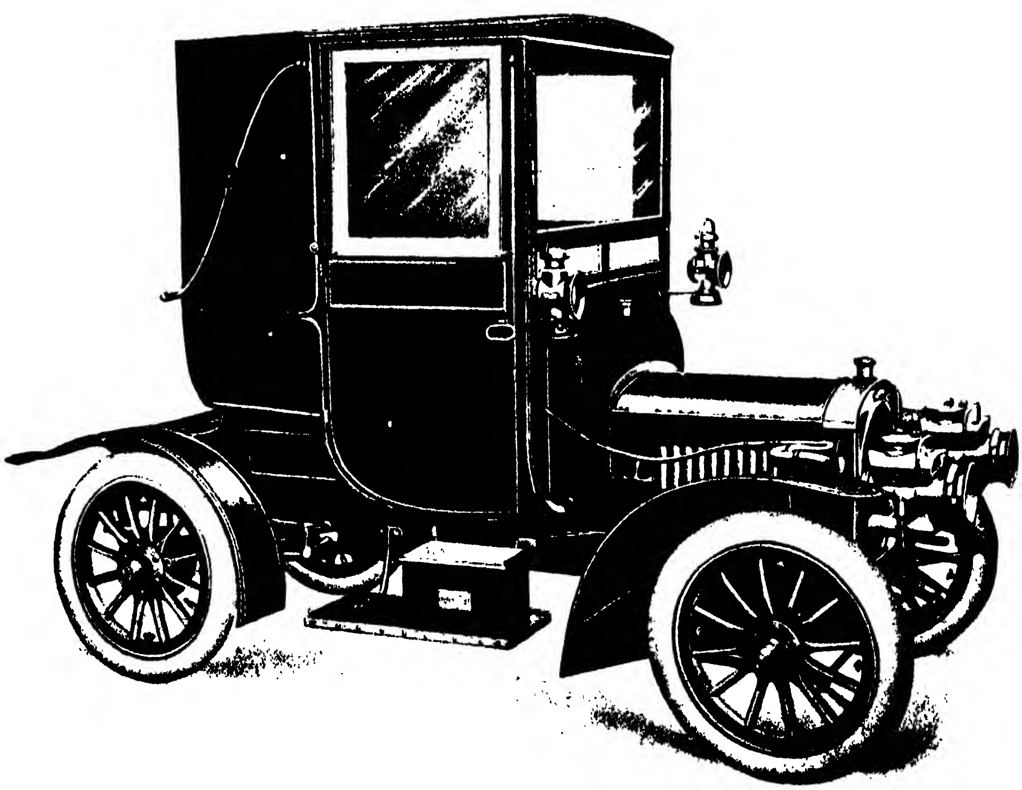


Fig. 485.—Doctor's Landaulette, by the Singer Car Company

mechanism must be adopted, such, for example, as the worm and sector, shown in fig. 476, in which the steering wheel is attached to the worm spindle and the axle arms to the sector.

The Car Body or Carriage Work.—There are now several well-recognized types of car bodies which have proved themselves best suited to the particular conditions which they are intended to meet. At one time the tonneau arrangement, illustrated in fig. 477, was largely used. It has corner seats in the rear of the tonneau, which, however, can only be entered from the roadway, as the door is situated at the back. The rear-entrance tonneau, on the other hand, does not necessitate a long wheel base, as does

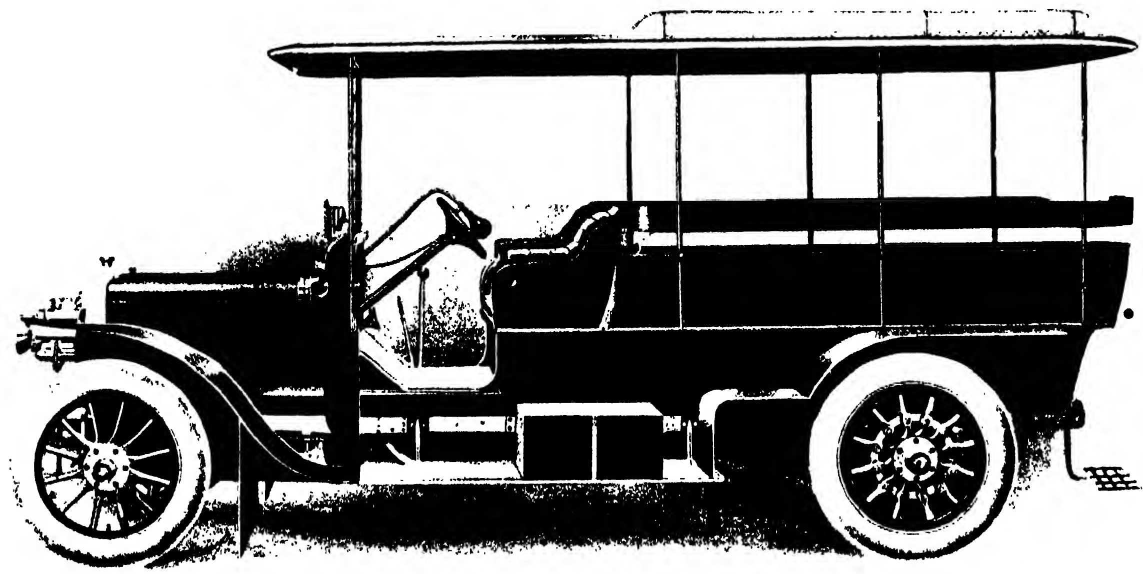


Fig. 486.—Daimler Twelve-seated Shooting Brake

the side-entrance type illustrated in figs. 478 and 479. Sometimes the rear seats of the phaeton tonneau may be entered from the front, as in fig. 480, which has one of the front seats so pivoted that it may be swung to one side. This figure also shows the bucket form of seat at the front, which is now very generally used. The single landaulette is shown in fig. 481, and the extended-front type of landaulette in fig. 482. Removable covers are frequently used, a common form being the Cape-cart cover, shown in fig. 483. When, on the other hand, the body has a permanent cover, it is known as the Limousine type, one example of which is given in fig. 484. A doctor's landaulette by the Singer Motor Company is illustrated in fig. 485, and a Daimler twelve-seated shooting brake in fig. 486.

STEAM CARS

It is not necessary to reconsider here the relative merits of steam and petrol cars, or the circumstances that have determined the great development of the latter type. At one time steam cars were sold in considerable numbers, but now this section of the industry is entirely in the hands of one or two manufacturers, who have brought it to a state of great perfection.

In outward appearance there is now very little to distinguish the steam car from the petrol, and the similarity is becoming still greater; but mechanically there is little that is common to the two types, as the essential organs are of very different natures. In the case of the petrol engine, the working substance, consisting of the oil vapour and air, has first to be compressed to a point suitable for ignition, and is then actually consumed in the engine cylinder at a very high temperature. It is then necessary to drive out the waste gases preparatory to drawing in the next charge. This sequence of operations constitutes the Otto cycle, which, as already explained, permits of only one working stroke in each cylinder during two revolutions of the crank. With steam as a working fluid, on the other hand, the actual generation of the vapour is effected in a separate boiler heated by means of an oil burner, and the steam is then expanded behind the working piston; but the power developed depends upon the degree of the expansion, and in this important respect the steam engine differs from the internal-combustion petrol motor. It is a more flexible system, so far as power is concerned, as by admitting a larger proportion of steam at each stroke extra power for hill climbing can be obtained as required. The power developed can be varied at the engine itself, to suit the needs of the car, instead of altering the speed by means of speed gears as in the petrol arrangement.

Steam has the undoubted advantage of greater flexibility, but so far as actual engine efficiency is concerned it cannot exceed one half that of the internal combustion motor, which has at present an efficiency of about 35 per cent.

Engine efficiency alone does not, however, determine the economy of a car, and the cost of the petrol or fuel is often a small charge compared with the upkeep of such parts as the tyres.

For the purpose of describing the details, two examples only will be given of actual cars. One of these is the American White car, which has been very successfully developed by the makers, and the other is the British Turner-Miesse car, manufactured at Wolverhampton. There are many types of steam wagons built in this country, but these cannot be dealt with here.

In addition to the usual chassis arrangements, the steam car comprises a steam generator with an oil burner for heating it; an engine of either the double- or the single-acting type, with the usual distribution valves and certain regulating devices for controlling the oil supply to the burner, and the feed supply to the boiler, the temperature of the generator, and the supply of steam. Water jacketing of the cylinders is not required, as it is in the petrol engine, but the radiator is retained, whereby the exhaust

steam is condensed and pumped back to the water tank. As the steam engine works expansively, and is controlled by means of the link gear, the speed-gear box common to cars of the petrol type is dispensed with.

The Generator. Fig. 487 shows the general arrangement of the 30-h.p. White chassis and the relative positions of the various parts. A view of the generator itself is given in fig. 488. It consists of a number of helical coils of seamless tubing, placed one above the other, and enclosed in a fire-resisting casing over an oil-fed burner. The coils of tubing are so connected that the water which enters at the top cannot flow by

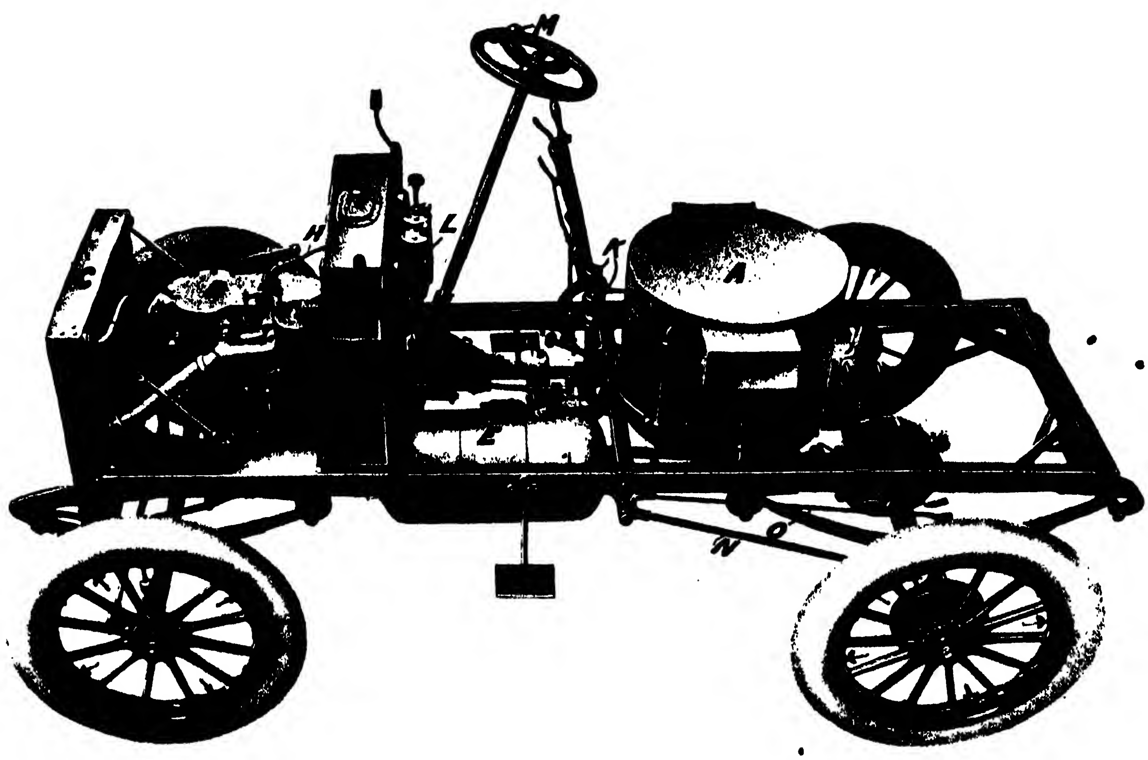


Fig. 487.—General Arrangement of 30-H.P. White Chassis

A, Generator; B, Cylinders; C, Condenser; D, Water tank; E, Fuel tank; F, Oil separator; G, Exhaust pipe; H, Cylinder lubricating pipe; J, Main steam pipe; K, Hand, air and water pumps; L, Power-operated lubricating pumps; M, Throttle operating wheel; N, Radius rod; O, Hand brake rod; P, Flue.

gravity through the successive lower coils, from which steam alone passes away at the bottom of the generator. The upper coils act practically as a water heater, and the water is converted into steam at some variable point in the lower coils, depending upon the demands of the engine. There is thus no water level to maintain, and no necessity for troublesome water gauges, while all danger of explosion is avoided.

Motor spirit, or petrol of all specific gravities up to 0.76, or the cheaper benzolene may be used as fuel for heating the generator tubes. Once the burner has been lighted and the engine started the action becomes entirely automatic, the temperature and pressure of the steam being maintained constant under all varying demands of the engine.

From the diagram, fig. 489, the generator feed water and the oil fuel systems may be traced through the various regulating devices. A represents the water tank,

A_1 the feed pump, A_2 the water regulator, A_3 the coiled tube inside the feed-water heater C; A_4 represents the flow regulator, A_5 is the thermostat, and A_6 the generator. These parts constitute the generator and the feed-water circuits. Oil fuel for the burner E_1 is stored in the tank B, and B_2 is the valve controlling its admission. To

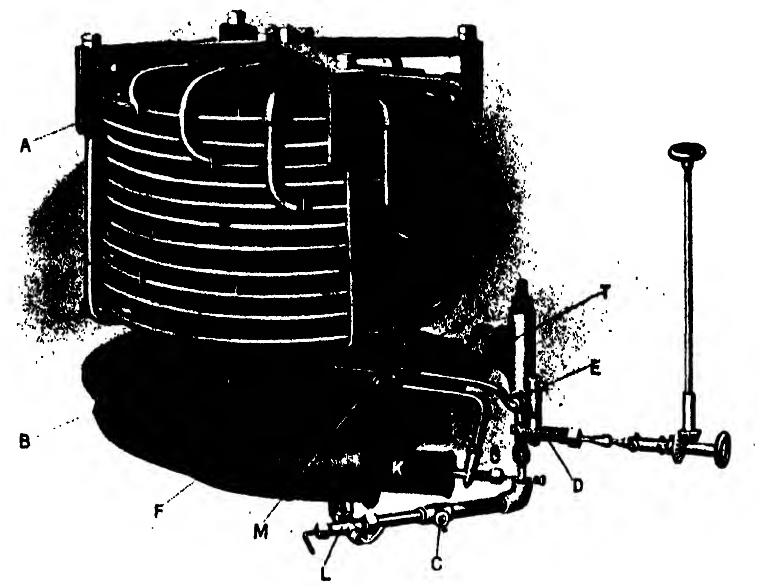


Fig. 488.—Steam Generator of White Steam Car

A, Top coil of generator; B, Main burner; C, Petrol main supply connection; D, Hand fire valve; E, Vaporizer-supply connection; F, Main vaporizer; G, Vaporizer nozzle; K, Mixing tube; L, Pilot light; M, Pilot-light cone; N, Generator superheating tube; T, Thermostatic valve.

start the generator from the cold condition there is provided a bypass valve B_3, by means of which oil may be admitted to the burner when there is no steam for the automatic supply. Under normal working conditions the water is drawn from the supply tank A by the engine-driven feed pumps A_1, and forced through the heater

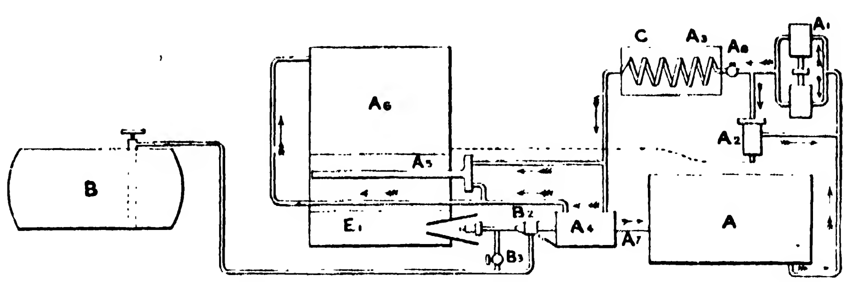


Fig. 489.—White Steam Car. Diagram of Oil-fuel and Feed-water System

coil A_3 to the flow regulator A_4. This regulator consists essentially of a cylinder in which works a plunger having throughout its length an open passage. At all times the water can flow through it to the generator, and in its passage it causes the plunger to move against the action of a spring to a distance depending upon the rate at which the water flows. When moved to the extreme end of its range the plunger opens a

bypass valve, which allows the water to return back through the connection A_7 to the water tank, and in this way the feed may be kept below a predetermined limit. To the plunger is also attached a needle which controls the fuel valve B_2, and thus regulates the action of the burner to suit the flow of water through the flow regulator A_4. If no water is being delivered by the pumps, the burner is completely shut off; but the valve B_2 is so shaped that a varying quantity of fuel passes through it, according to the position of the plunger. An independent pipe connection is made direct to the boiler from the feed heater A_3, through the thermostat A_6, instead of the flow regulator. Under normal running conditions, with the thermostat moderately cool, the valves of

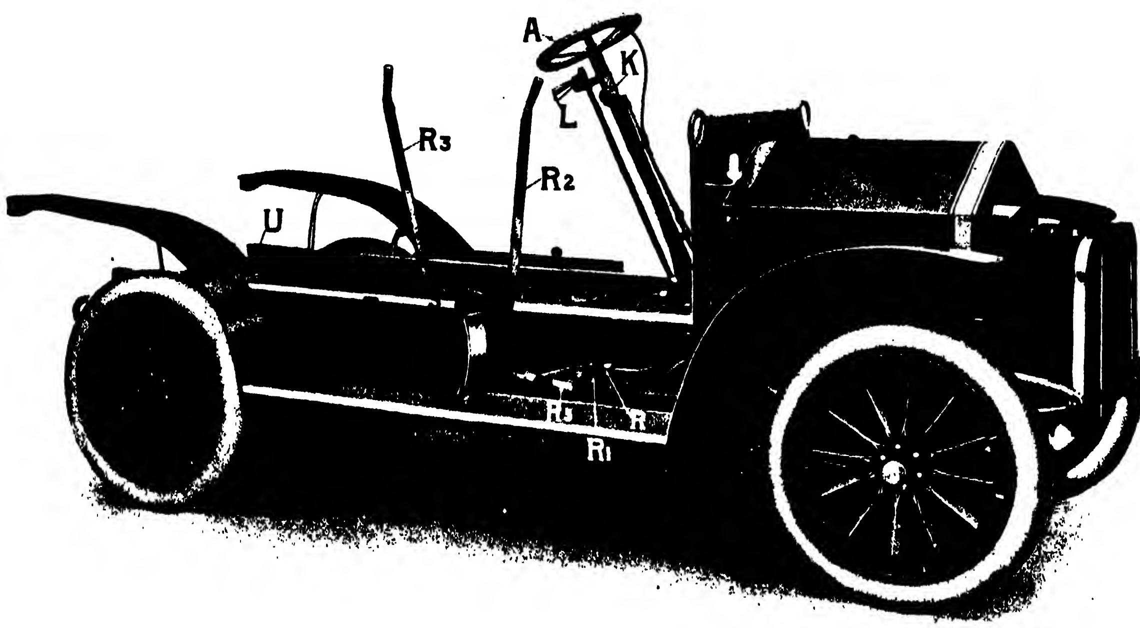


Fig. 490.—Chassis of Turner-Miesse Steam Car

A, Bypass valve regulator lever; K, Pressure-relief valve wheel; L, Cam-shaft lever controlling valve lifts; R R_1, Mechanical pump valves; R_2, Hand-pump lever; R_3, Rear wheel brake lever; R_5, Hand operated pump; S, Paraffin tank; T, Water tank; U, Petrol tank.

this subsidiary circuit remain closed; but if the temperature rises to a certain point, the thermostat opens the valve and allows an additional flow of water to enter the boiler tubes, with the result that the proportion of feed water to oil-fuel supply is increased, until the temperature of the generator becomes again reduced to the normal. By the combined action of the thermostat and the flow regulator the water and fuel supplies are so proportioned as to maintain at all times an approximately constant steam pressure and temperature whatever the demand for steam may be. To make the action of the system completely comprehensible it is necessary to point out that the maximum heat generated by the burner is sufficient to immediately vaporize the water at the maximum rate ever required, and on the other hand that the maximum flow of water that is possible through the regulator is well below the quantity that the burner is capable of evaporating and instantly superheating to the full extent. It follows,

therefore, that the generator can never be flooded, and that under any working conditions the pressure can never rise to an abnormally high degree.

In the Turner-Miesse steam car, the chassis of which is illustrated in figs. 490 and 491, the generator is of a similar flash type, consisting of a series of tubes in several layers arranged above the main burner, which is fed with petrol and paraffin.

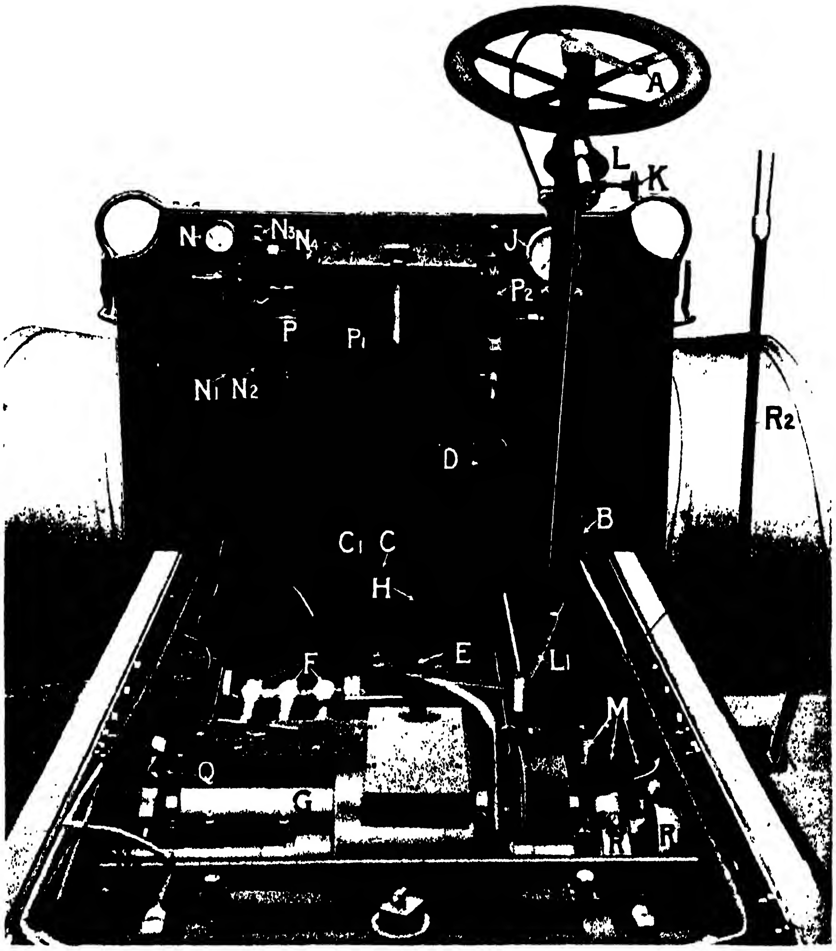


Fig. 491. General Arrangement of the Turner-Miesse Engine. Control Arrangements and Dashboard

A. Water bypass valve regulator lever.
B. Bypass valve from pumps to main water tank.
B_1. Return from bypass to water tank
C. Water relief pipe from generator to relief pipe.
C_1. Down-draught flue of generator.
D. Combined throttle and brake pedal.
E. Steam disc throttle.
F. Engine-valve inlets.
G. Crank and reducing gear case.
H. Steam condensing coil.
J. Steam-pressure gauge
K. Pressure relief wheel.
L. Cam-shaft lever, controlling valve lifts.
M. Feed-pump delivery valve.
N. Pressure-gauge fuel tank.
N_1 Pressure pipe from air pump Q.
N_2. Air-pressure pipe to fuel tanks.
N_3. Blow off relief valve.
N_4. Pressure-relief pipe.
N_5. Branch from N_2 to petrol tank.
N_6. Branch from N_2 to paraffin tank.
P. Lubricator for Q.
Q. Fuel-tank air pump.
R R_1. Mechanical water-pump eccentrics.
R_2. Hand water pump starting lever.
R_3. Hand brake for rear wheels.
R_4. Engine foot brake.
S. Paraffin tank.

For the 10-h.p. car generator sixteen layers of weldless steel tubes connected together in four sections are used, and the connections are so arranged that only highly superheated steam can be taken from the section in direct connection with the engine throttle. An illustration of the burner arrangement is given in fig. 492, which shows also the pilot burner necessary for starting up the main burner. To burn petrol or paraffin successfully, and without smell, it is necessary first to vaporize it, and this is done in the coils B_1 B_1 shown in the figure. When starting from the cold condition

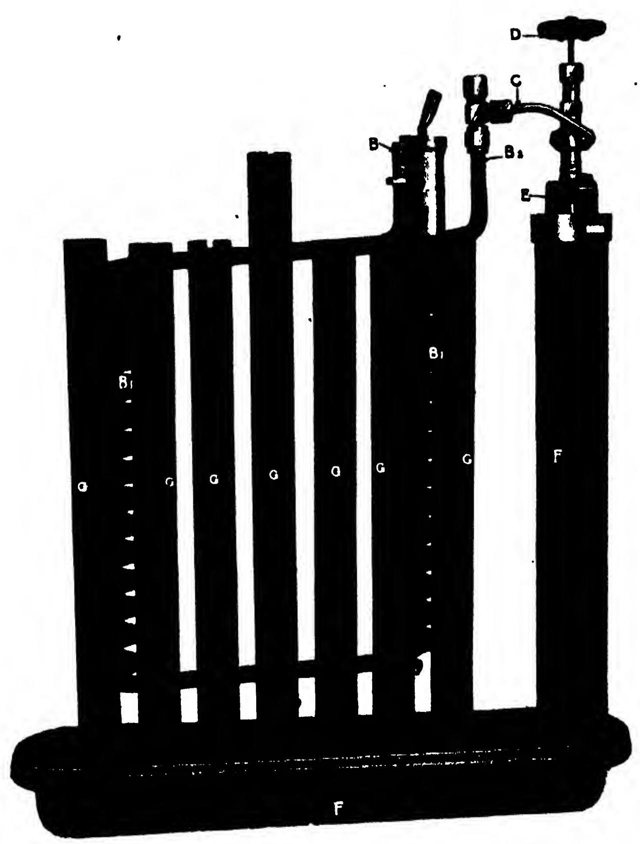


Fig. 492.—Burner of Turner-Miesse Steam Car

A, Pilot-burner nozzle; B, Petrol inlet to vaporizer coils; B_1B, Fuel-vaporizer coils for main burner; B_2, Vapour connection from B_1; C, Connection to main-burner nipple; D, Cleaning and regulating valve for main burner; E, Main-burner nipple; F F, Fuel-mixing chamber; G, Main burner tubes.

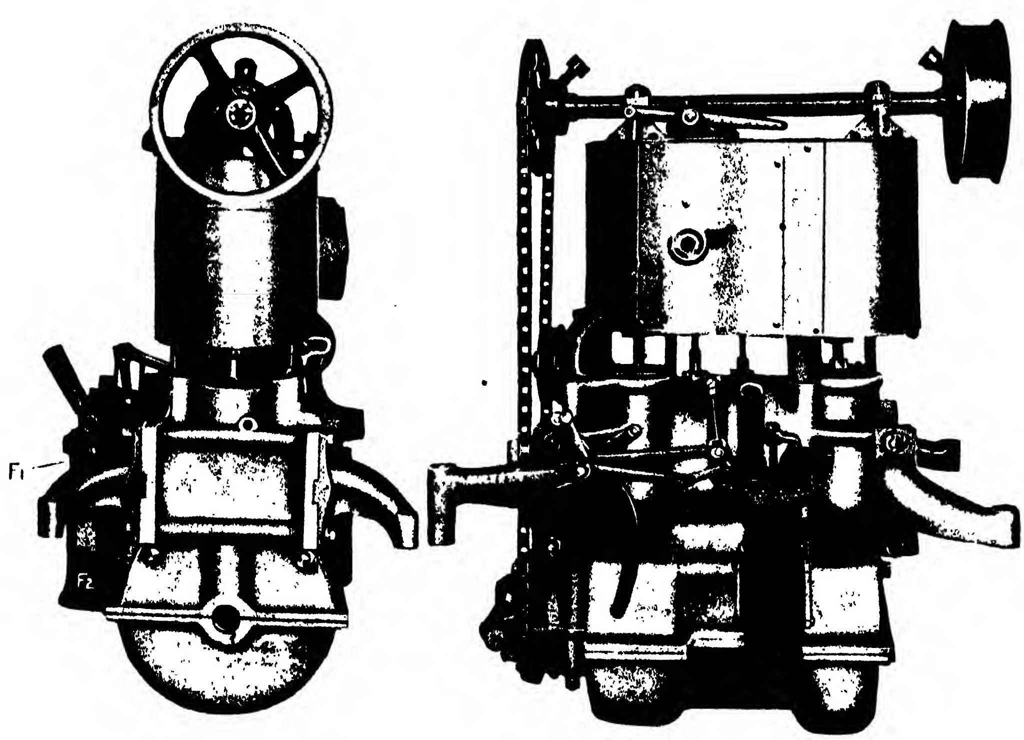


Fig. 493. 30-H.P. White Steam Car Engine. End and Side Elevations

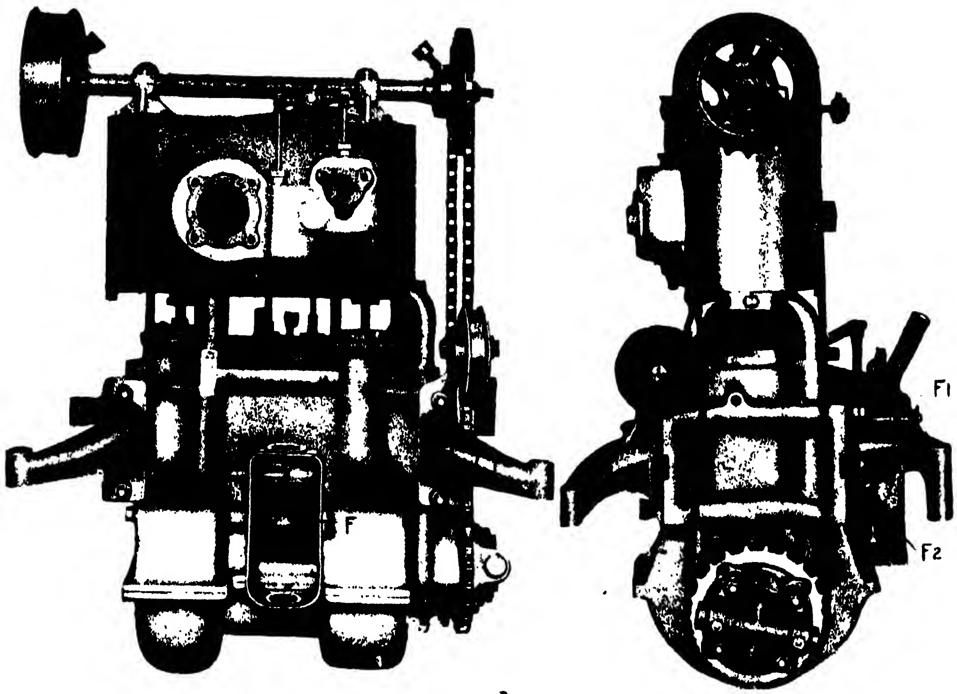


Fig. 494. 30-H.P. White Steam Car Engine Side and End Elevations

the pilot burner must first be lighted, as follows. About a thimbleful of petrol is poured into a cup beneath the pilot-vaporizer coil, and then lighted with a match. The heat of the burning petrol warms the pilot vaporizer, and after a minute or two, by opening

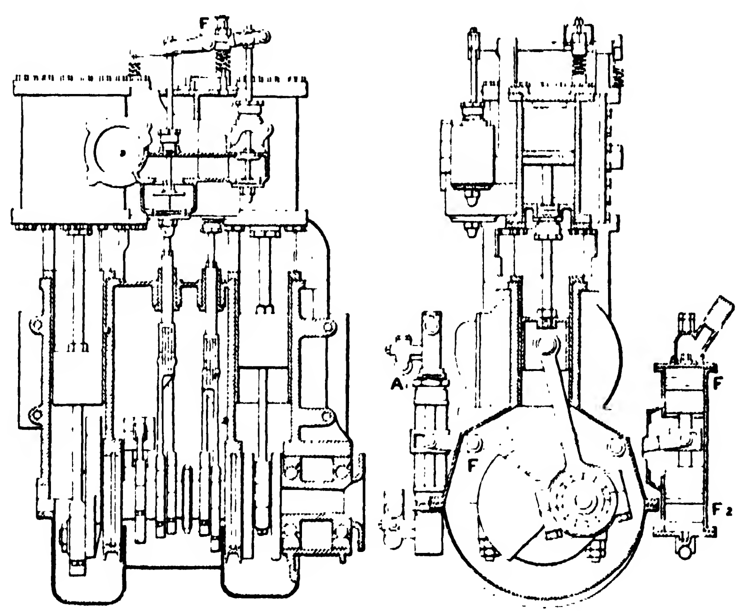


Fig. 495. Side and End Sectional Elevations of 30-H.P. White Engine

an oil-supply valve, a stream of petrol is forced through the pilot nozzle by the pressure of air stored for the purpose in a special reservoir. In its passage through the coil the petrol vaporizes and burns in contact with the air at the pilot nozzle. This pilot flame in turn heats one of the main-burner coils B_1 to a high temperature. After

a few moments petrol is allowed to circulate in the heated tube, and the vapour produced then passes through the connection C, and the needle valve controlled by the hand wheel D, to the mixing chambers F, from whence it passes to the burner tubes G, where it is ignited by the pilot-burner flame, which is then turned off. As the temperature rises the petrol supply is gradually reduced, and the paraffin correspondingly admitted to the burner, until under normal working the petrol is entirely shut off.

The Engine.—In the White car the engine, which is shown in figs. 493, 494, and 495, is of the double-acting two-cylinder compound type, while in the Turner-Miesse car a three-cylinder single-acting engine, arranged horizontally, is used, thus

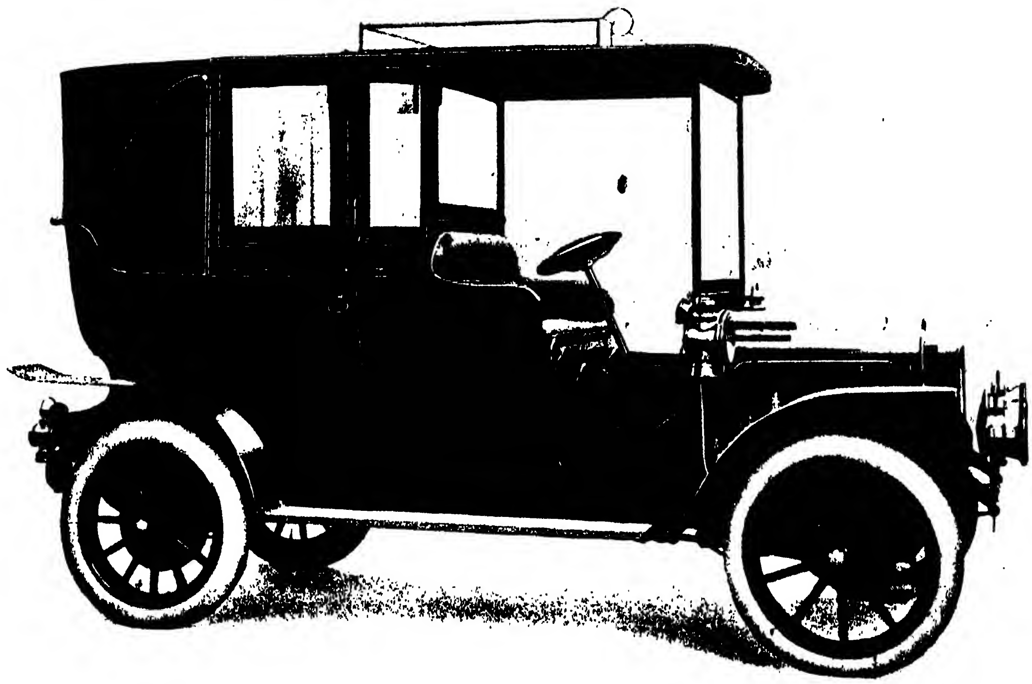


Fig. 496. 30-H.P. White Steam Car

following more on the lines of the internal-combustion motor, although the cycles are essentially very different. Referring to the illustrations of the White engine, it will be seen that the cylinders are arranged vertically, with the main shaft carried on ball bearings at the bottom. Cylinders of 3 and 6 in. diameter, with $4\frac{1}{2}$-in. strokes, are used, and the steam is admitted to the high-pressure cylinder through a piston valve, and to the low-pressure through the ordinary type of flat slide-valve. Under normal running conditions the engine works compounded and expansively; that is to say, the steam, after being usefully expanded in the high-pressure cylinder, is further expanded in the low-pressure cylinder, before being exhausted to the condenser. Extra demands for power, as for example in hill climbing, are met by cutting off the steam at a later period of the stroke; and when the demand is exceptionally great, as when starting from rest, live steam may also be admitted to the large cylinder through a special

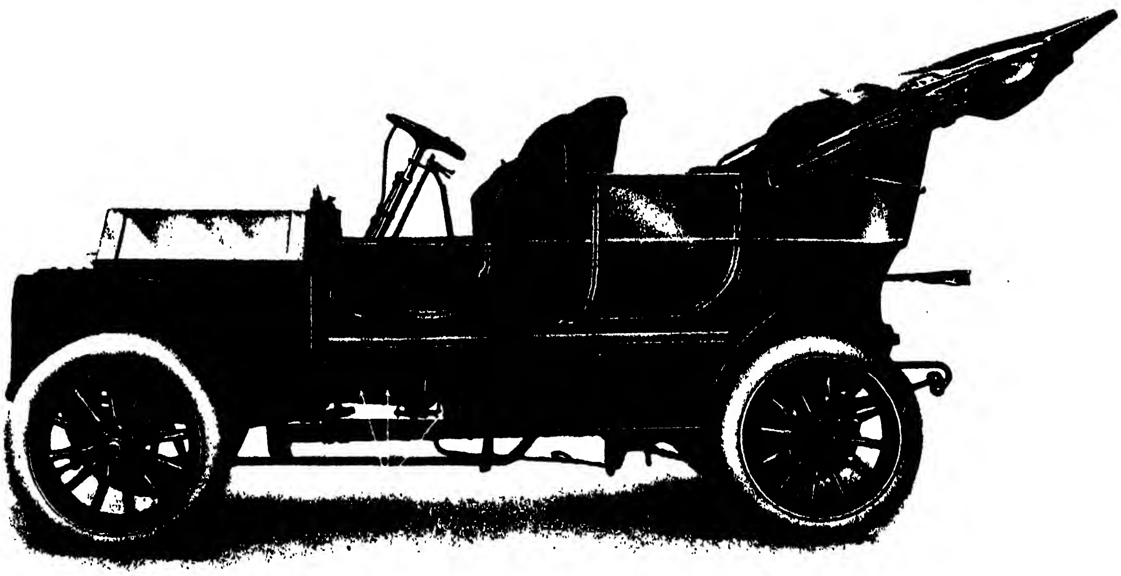


Fig. 497. Left-hand Side Elevation of the Turner-Miesse Steam Car, showing the three starting hand wheels (8) for operating the burner fuel supply

Simpling valve. Fig. 496 shows the external appearance of the White steam car of 30 h.p., and fig. 497 the Turner-Miesse car, with the three hand wheels for starting the burners exposed at 8.

ELECTRIC CARS

For city work, where smooth and quiet running are of more importance than actual economy of working, the electric vehicle is exceptionally suitable; but its universal adoption is limited by the great weight of the storage cells, and by the necessity for recharging after from 30 to 40 miles of running over average roads in fair condition. If a more compact system of storing electrical energy in a condition suitable for its reconversion into mechanical energy could be devised, the objections to the electric car for general purposes would disappear; but at the present time none of the many promises has been fulfilled, and there are no indications that the difficulty will soon be solved.

A storage battery, or, as it is called, an accumulator or secondary cell, consists of two sets of lead-pasted plates immersed in water, which is slightly acidulated to facilitate the chemical reactions and to decrease the internal resistance of the cell. One of the plates is generally composed of lead alone, and is known as the negative plate, while the positive one consists of a porous lead plate having the interstices filled with a paste of lead dioxide. In the discharged condition the paste on the positive plate is really in the condition of lead sulphate, while the surface of the negative plate is coated with a layer of lead oxide. The process of charging an accumulator then consists in passing current from the supply mains through the cell, where the electrical

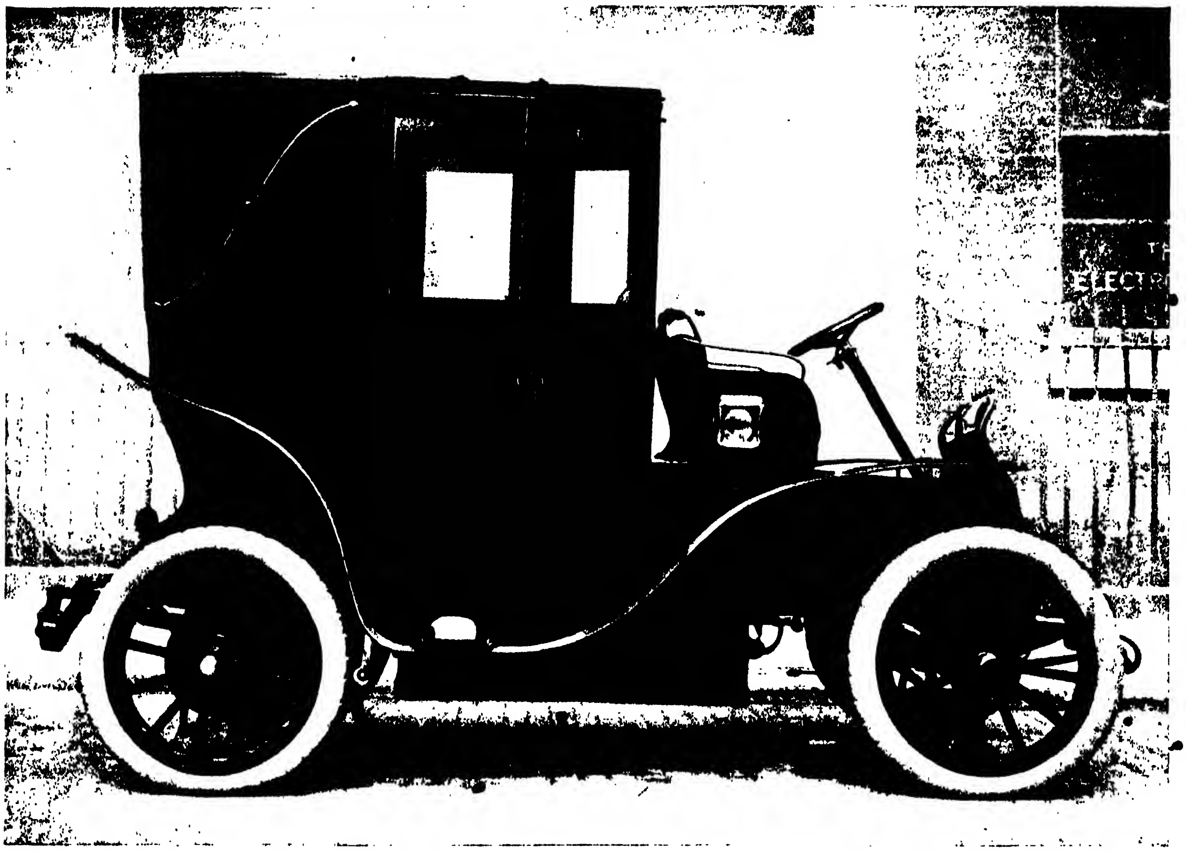


Fig. 498.—8-B.H.P. Electromobile of the London Electromobile Company

energy is expended in changing the chemical conditions of the two sets of plates. The paste on the positive plate is converted from lead sulphate to lead dioxide at the expense of the negative plate, which becomes deoxidized and converted into the metallic condition. These reactions are reversed during the discharge of the cell, that is, the positive plate becomes sulphated and the negative plate oxidized as the store of electrical energy is withdrawn. Care must be taken to recharge the cell before the whole of the energy is withdrawn, and not to discharge at too high a rate, as otherwise the plates may buckle to a serious extent owing to irregular or too rapid expansion of the materials. Between one pair of plates there exists a definite voltage, determined by the chemical conditions. When fully charged, the voltage of each cell should be about 2.2 volts, and the cell should not be allowed to discharge below 1.9 volt at the lowest.

Since for motor-car purposes it is necessary to provide a pressure of about 100 volts, a series of about forty-five to fifty cells, each giving an average of 2 volts, must be carried on the car. There is also a limit to the quantity of the current that can be drawn from each square foot of plate area, so that for a definite power the battery as a whole must have a certain capacity, and therefore a certain weight, which is generally considerable, and sometimes about 33 per cent of the total weight of the car.

It is not possible to do more than refer to the essential features of electric carriages, and for the purposes of description the carriage of the London Electromobile Company will be taken as a typical example.

Fig. 498 illustrates the type of electromobile so frequently seen upon the London streets, and figs. 499 and 500 show the arrangement of the chassis in side elevation and plan.

The chassis frame, to the under side of which is slung the battery box, is straight in elevation and rectangular in plan, and is constructed of rolled channel section. This arrangement of the box has been adopted to obtain (*a*) rapidly interchangeable batteries; (*b*) even distribution of the weight over the wheels; (*c*) the collection of all the cells in one box, to facilitate thorough inspection, and to simplify the manipulation; and (*d*) to lower the centre of gravity with a view to minimizing side slip. With the underslung arrangement of the battery there is the further advantage that any acid fumes escape at once to the outside air, and do not destroy the wood-work and

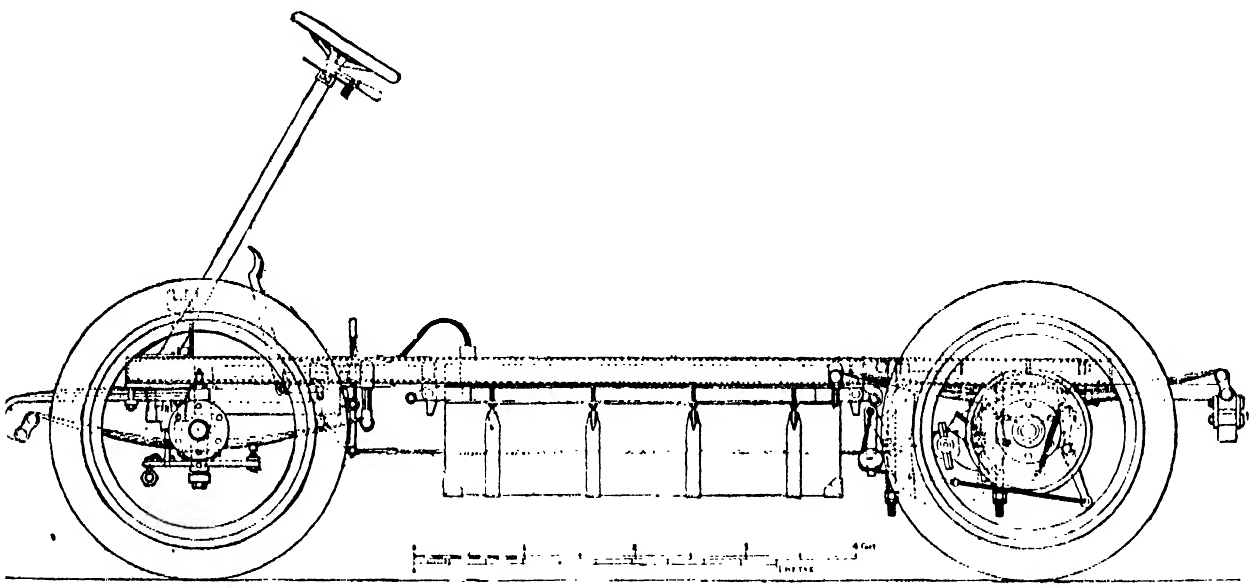


Fig. 499.—Electromobile Chassis. Side Elevation

cushions, or affect the atmosphere inside the carriage. The battery case is attached by suitable lugs and taper pins to the under side of the frame, and it may be readily removed when in the garage for recharging, or to facilitate the cleaning of the chassis.

The battery consists of about forty-five cells, weighing, apart from the case, about 10 cwt., and has a capacity of 135 ampere hours, equivalent to a continuous discharge of, say, 27 amperes for five hours. This current, at the pressure of 90 volts, is sufficient to drive the carriage illustrated in fig. 498 for 40 miles under average conditions. Each plate of the battery is formed of two thin grids of antimoniated lead, riveted together and perforated with thirty-two square holes, into which pellets of the active paste are forced under hydraulic pressure. It is found that the plates so constructed last under ordinary working conditions for about twelve months, and when worn out they may be readily replaced at small cost.

A series-wound bipolar motor of the ironclad type converts the electrical energy of the battery into mechanical energy, and applies it to the driving of the rear axle. When working continuously, the available power is 8 brake h.p., but for short periods

a load of double this amount may safely be carried without unduly overheating the motor.

From the motor the drive is transmitted through a double train of double helical gearing to the differential, and thence to the hubs of the rear wheels by live shafts, which revolve in an external tubular axle of sufficient strength to preserve the driving axle from all bending stresses. All the gears run in oil, which is circulated through each of the bearings in turn, until ultimately it escapes at the road wheels.

By means of the controller, forward speeds of from 3 to 15 miles an hour, with one reverse speed, may be obtained in addition to the operation of two electric brakes. It is of a simple and compact design, and is enclosed in a cast aluminium casing bolted in a horizontal position to the under side of the chassis. Immediately under and parallel

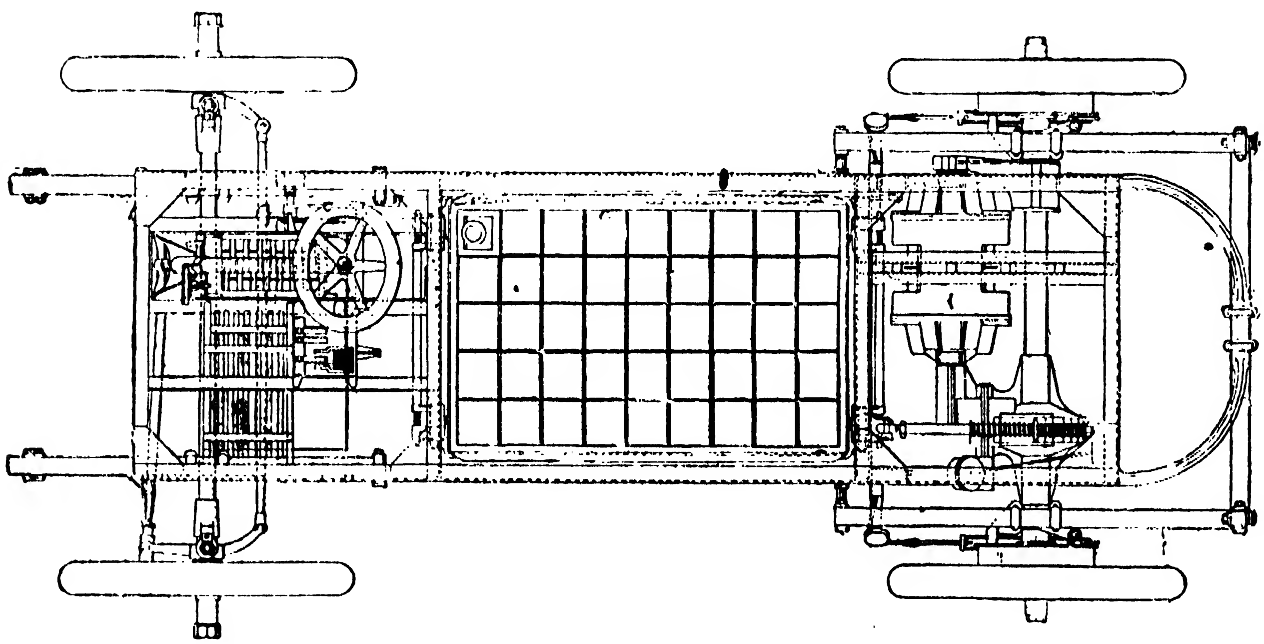


Fig. 300. Electromobile Chassis. Plan

with the steering wheel is placed the controller hand wheel, as this position is found to be the most convenient for the driver. It is mounted upon a tube concentric with the steering spindle, and actuates the controller brushes through bevel gears and a rachet mechanism, which prevents any lingering between the positions of contact. As the normal speed is not great it is sufficient for the steering of the car to transmit the motion of the steering wheel to the axle levers directly through ordinary bevel gears having a ratio of 1 to 4. This dispenses with the customary irreversible arrangement of worm and sector, which requires to be frequently readjusted to eliminate backlash, due to wear.

In addition to the two electric brakes already mentioned, a powerful double-acting expansion brake is fitted on the hubs of the rear wheels. It is applied by a foot pedal, and the pressure on the two wheels is equalized by means of a wire rope led over suitable pulleys. To prevent the undue overloading of the motor that would take place if the brakes were applied before the current was cut off, a special quick-break switch is provided. When the foot pedal is slightly depressed the current is

cut off, and the car runs freely, until by further depressing the pedal the brake comes into action. On releasing the pedal the process is reversed, that is, the brake is released before the current is switched on to the motor.

Certain manufacturers are now combining the petrol engine and the electric-motor systems with a view to dispensing with the use of accumulators and change-speed gears while retaining the desirable features of both the systems. Current for the motor is generated by a dynamo driven from the engine, but the combined arrangement has so far only been applied to commercial vehicles of the heavier classes, and its general adoption is as yet a question of future development.